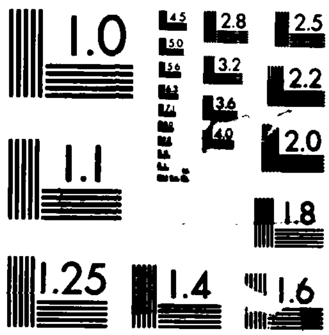
AD-A186 923 THE USE OF COST ESTIMATING RELATIONSHIPS VERSUS ACCOUNTING MODELS FOR EST..(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF SYST R S VERMA 1/2

UNCLASSIFIED SEP 87 AFIT/GSM/LSQ/87S-35 F/G 5/3 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

THE USE OF COST ESTIMATING RELATIONSHIPS VERSUS ACCOUNTING MODELS FOR ESTIMATING MAINTENANCE AND REPAIR COSTS: A METHODOLOGY DEMONSTRATION

THESIS

Rajiv S. Verma
First Lieutenant, USAF

AFIT/GSM/LSQ/87S-35

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY
AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

AFIT/GSM/LSQ/87S-35

DTIC
ELECTE
DEC 1 1 1987
S D
H

THE USE OF COST ESTIMATING RELATIONSHIPS VERSUS ACCOUNTING MODELS FOR ESTIMATING MAINTENANCE AND REPAIR COSTS: A METHODOLOGY DEMONSTRATION

THESIS

Rajiv S. Verma
First Lieutenant, USAF

AFIT/GSM/LSQ/87S-35

Approved for public release; distribution unlimited

AFIT/GSM/LSQ/87S-35

THE USE OF COST ESTIMATING RELATIONSHIPS VERSUS ACCOUNTING ACCOUNTING MODELS FOR ESTIMATING MAINTENANCE AND REPAIR COSTS: A METHODOLOGY DEMONSTRATION

THESIS

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Engineering Management

Rajiv S. Verma, B.S., M.B.A.

First Lieutenant, USAF

September 1987

Approved for public release; distribution unlimited

Acknowledgements

I am deeply grateful to my advisor, Mr. Richard L. Murphy, for his advice, guidance and in particular, his patience. Despite having an enormous responsibility of being the thesis advisor to three students and serving as reader for two others, he made time available whenever it was needed.

Another instrumental person in the completion of this thesis is Mr. Roland Kankey whose assistance with computer programs was invaluable. I am also indebted to Captain Javier Flores of AFLC/LOC for sharing his expertise about the maintenance of jet engines and for tolerating my numerous impositions on his time.

I cannot be thankful enough to Pat Norton, my typist, who under a tremendous constraint of time, transformed what was a disarrayed mixture of text, equations and tables, into a presentable form.

Finally, I would like to thank my wife, Chand, and my brother, Sanjiv. They provided me with continuous emotional support which I needed during the many anxious moments that arose while trying to complete this effort.

Rajiv S. Verma

Table of Contents

List of Figures

List of Tables

AFIT/GSM/LSQ/87S-35

Abstract

This thesis demonstrated a methodology of developing a Cost Estimating Relationship (CER) that is capable of generating nearly the same cost estimates as an accounting type of cost model. A cost model was first developed that estimated annual recurring maintenance and repair associated costs of a jet engine. This model used 51 input variables and 30 equations and represented an accounting approach to cost estimating with input requirements at low levels of detail. Using techniques of multiple linear regression, a CER was developed that used only seven aggregated variables to estimate the same cost at an acceptable level of accuracy.

The emphasis in this thesis is on the demonstration of a methodology that can be used to develop CERs. Both the accounting type cost model and the CER in this thesis are exclusively for the validation of a methodology and were developed using an artificially generated data base. As such they are not valid for any cost estimation purposes.

THE USE OF COST ESTIMATING RELATIONSHIPS VERSUS ACCOUNTING MODELS FOR ESTIMATING MAINTENANCE AND REPAIR COSTS: A METHODOLOGY DEMONSTRATION

I. Introduction

General Issue

Air Force Regulation (AFR) 800-11, Life Cycle Cost Management Program, defines life cycle cost (LCC) rather simply: "the total cost to the government for a system over its full life" (1:1). The life of a system can be divided into four distinct phases: (1) research and development (R&D), (2) acquisition or production, (3) operation and support, and (4) disposal (25:9).

Operation and support (O&S) costs often make up a substantial portion of LCC (22:1). While these costs are not incurred until the system is actually in the inventory, the decisions that determine these costs usually have to be made prior to production (24:1.2). Therefore, in order to make good acquisition decisions, it is very important to know what the life cycle cost implications of each alternative might be. This would require that one have some idea of what the O&S costs are under each alternative.

O&S cost estimation, often called life cycle costing, can serve a number of objectives (25:11): (1) to determine what the total costs are and what the expenditure profiles

look like so that one can assess the budget impact in the out years, (2) to determine economically feasible performance requirements, and (3) to provide design guidance to reduce O&S costs.

Cost Estimating Methods

Within DOD, there are several generally accepted cost estimating techniques: detailed estimating, cost estimating relationships (CERs), expert opinion and estimating by analogy are some of them (5:9). No one method is the best; the appropriateness of any method depends on the situation. For instance if one is trying to cost a new system, something that perhaps represents a quantum leap in technology and for which there is no data base, one may be forced to develop the estimate by asking the opinion of people who are most knowledgeable about the system. This is the "Expert Opinion" approach where the cost analyst seeks, as the term suggests, the opinion of an expert or experts about the system being estimated. This method is purely judgmental and as such it involves a lot of subjectivity on the part of the "experts."

The method of estimating by analogy method is less subjective. According to this method, the cost analyst compares the new system to an already existing system that is most similar to it. Using the cost of the existing system as a starting point, the estimator then adjusts the cost based on the differences between the two systems.

Detailed cost estimating can further be divided into two categories: the engineering build-up method and accounting type cost models. The engineering build-up method builds a cost estimate by summing up costs of low levels of hardware breakdown and disassembly. This "bottom up" method uses the "sum of parts" approach to approximate the whole. Using a work breakdown schedule (WBS), the engineering build up method identifies components at a very detailed level and sums its way up to higher levels of aggregation.

Accounting type of cost models are similar to the engineering build-up method in the amount of detail involved. However, while engineering build-up method concentrates on components, the accounting type of cost models are activity oriented. They account for cost by identifying activities at low levels and by summing the associated costs (9:17).

Cost estimating relationships (CERs) are statistical models which treat cost as a function of selected variables. These variables are called cost drivers; they drive cost in the sense that their influence on cost is rather substantial. Since the selection of input factors in CERs is rather discriminatory, i.e., the variables chosen have to be significant in terms of their impact on cost, CERs are not nearly as large as accounting models.

Problem Statement

Research seems to indicate that most O&S cost models are accounting type of models. These models try to estimate O&S cost by describing the operation and support process of the system itself. Consequently, they normally include a large number of variables that correspond to the many activities that make up the O&S cost effort. This property does have its advantages:

1. Costs can be tracked more readily because they are more visible; this can lead to easier management of O&S dollars.

2. The amount of detail in the model lends itself to sensitivity analyses and tradeoff decisions.

However, accounting models require detailed information. During the early phases of the acquisition cycle, there is insufficient operational information on the new system to provide as much data as the accounting model needs. The use of an accounting model also requires having to estimate values for a large number of variables. This may require an amount of time that may not be available.

Assuming that the required time is available, estimating a large number of variables may inadvertently result in estimating errors. One could argue that in estimating a large number of variables, errors have a way of balancing out so that the overall estimate is still reasonably accurate. The underlying concept here is that an

over-estimation of one variable may nullify the under-estimation of another so that in totality things have a good chance of coming out even. The fallacy with this argument is that variables have different weights, i.e., their impact on cost could range from miniscule to very significant. Thus, an over-estimation of a very significant variable cannot be balanced out by an under-estimation of a variable that has minimal impact on cost and vice-versa.

Estimating errors may also be caused by a bias in the estimating process. In estimating a large number of variables, there is a tendency to estimate them in a normative manner, i.e., to estimate them as they should be. This kind of an optimistic approach tends to ignore the effect of problems and complexities that are a part of the normal operating environment and therefore may under-estimate actual costs.

During the early phases of the acquisition cycle, the purpose of an O&S cost estimate is primarily budgetary. At this point, the decision makers are more interested in an aggregate total O&S cost rather than a detailed breakdown of this cost among components and sub-components. If a model could estimate costs equally well while using a significantly lesser number of variables, the purpose would be served just as well. Cost estimating relationships can do just that. They do so by a careful identification of the input variables; if one variable can capture the effect that

several variables are having on cost, then it makes sense to only include that one variable and not the others if an aggregate cost estimate is what is desired.

There may be some apprehension that doing this increases the potential for estimating error, that is to say that since there are fewer variables and they are all significant in terms if their impact on cost, an estimation error in any one variable is likely to have a more serious impact on estimated cost. However, the task of estimating a much lesser number of variables means that more time can now be devoted to estimating each variable, thus increasing the opportunity to achieve greater accuracy. Besides, a variable that is significant in the CER is also likely to be one of the the more influential variables in the accounting type of model. Therefore, an error in its estimation would have a negative impact in either case.

Some Myths about Detail and Accuracy

The following two phrases are often heard in connection with military cost analyses:

1. We must always strive for a high degree of accuracy in an absolute sense.
2. A higher degree of accuracy can be attained by going into a greater amount of detail [13:76].

In the context of long range planning, the possibility of accomplishing a high degree of accuracy in the absolute

sense is remote. This is so because of the characteristics of long range planning. These characteristics include uncertainties, lack of detailed information and data, and a wide range of alternatives. Under these conditions, highly accurate cost estimates are most unlikely. This is not critical because most long term planning efforts require relative comparisons between alternatives. If the cost estimates provide sufficient information to facilitate the best decision, then they have served their purpose. Analytical cost estimating techniques which treat alternatives consistently are better suited for comparative cost analyses.

> It is important to understand these points because in the long-range planning context the analyst can waste much time and effort if he tries to pursue an objective as elusive (and perhaps as irrelevant) as a high degree of accuracy in an absolute sense [13:76].

The second statement, "a higher degree of accuracy can be attained by going into a greater amount of detail" is generally not true and particularly false in the context of long range planning. Under conditions of knowledge gaps and paucity of data, to force the analysis into a finer and finer grain of detail will force the analyst into essentially using fictitious numbers to fill in the categories that are overly detailed (13:76).

> In such instances, concentrating the analytical effort at an appropriate (relatively high) level of aggregration and using carefully derived

estimating relationships are the most likely means of producing fruitful results [13:77].

Research Objective

Having established that accounting models are not really necessary nor suitable for O&S cost estimation during the early part of the acquisition cycle, the purpose of this research effort is to demonstrate the feasibility of using cost estimating relationships models to estimate O&S costs. The researcher will attempt to do this by by demonstrating that it is possible to develop a CER that is capable of generating nearly the same cost estimates as the accounting model.

Scope

Both the accounting model and the CER estimate the annual recurring costs required to repair and maintain jet engines. However, the methodology demonstrated in this document is not limited to either jet engines or to the repair and maintenance element of O&S costs; it can be applied to any system or to any element of O&S costs.

The development of the CER is limited to those models that can be expressed as a linear function or as a transformed linear function. This allows the use of the Least Squares Best Fit method in determining the model parameters.

The CER will be evaluated within the context of the normal regression model.

Research Questions

In order to accomplish the objective stated above, the following research questions will be addressed:

1. Identification: What new variables should be created from the inputs into the accounting model? What variables should be considered for inclusion in the CER?

2. Specification: What is the functional relationship of the dependent variable, cost, with the independent variables, the cost drivers?

a. Does cost increase or decrease with an increase or decrease in a particular variable?

b. Is this relationship linear? If not, can it be transformed into a linear relationship by transforming the independent variables?

3. Model Description: What is the nature of the relationship between cost and the cost drivers represented by the CER?

a. What is the influence of each independent variable on cost?

b. What are the standardized regression coefficients, and what do they mean?

4. Model Statistics: What are the statistical properties of the CER?

a. Does each individual variable make a significant contribution to the CER's ability to explain cost?

b. What is the overall statistical significance of the CER?

5. Model Diagnostics: How is each independent variable correlated with the other independent variables in the CER? Are any of the observations outliers, and if so, what is their impact on the analysis?

a. Do the error terms have a constant variance?

b. Are they normally distributed, and are they independent of each other?

6. Predictive Ability of the Model: How well does the CER predict cost?

a. How accurately does the CER predict the observations in the data set?

b. How wide are the prediction intervals in comparison to the magnitude of the predicted value?

II. Background

Repair and maintenance costs are part of the operation and support costs which in turn are a significant portion of the total life cycle cost of a jet engine. Chapter I briefly introduced the idea of Life Cycle Cost (LCC). This chapter discusses the subject in greater detail, particularly in the context of defense acquisition.

The Acquisition Cycle

In order to understand the importance of the LCC concept, it is first necessary to understand some basic concepts of the acquisition process of weapon systems. The literature suggests that the life cycle of a system is normally divided into four phases: (1) Research and Development (R&D), (2) Production, (3) Operating and Support, and (4) Disposal (25:9; 6:1; 16:2-1).

Research and development (R&D) can be further subdivided into the conceptual phase, the validation phase and the full scale development phase (25:9). Likewise, the first phase of the Operating and support is initial deployment. The three phases of R&D, Production, and the initial deployment phase of Operating and Support constitute the acquisition cycle, as shown in Figure 2.1.

1. Concept Exploration: A statement of need describes an operational deficiency or need and is initiated

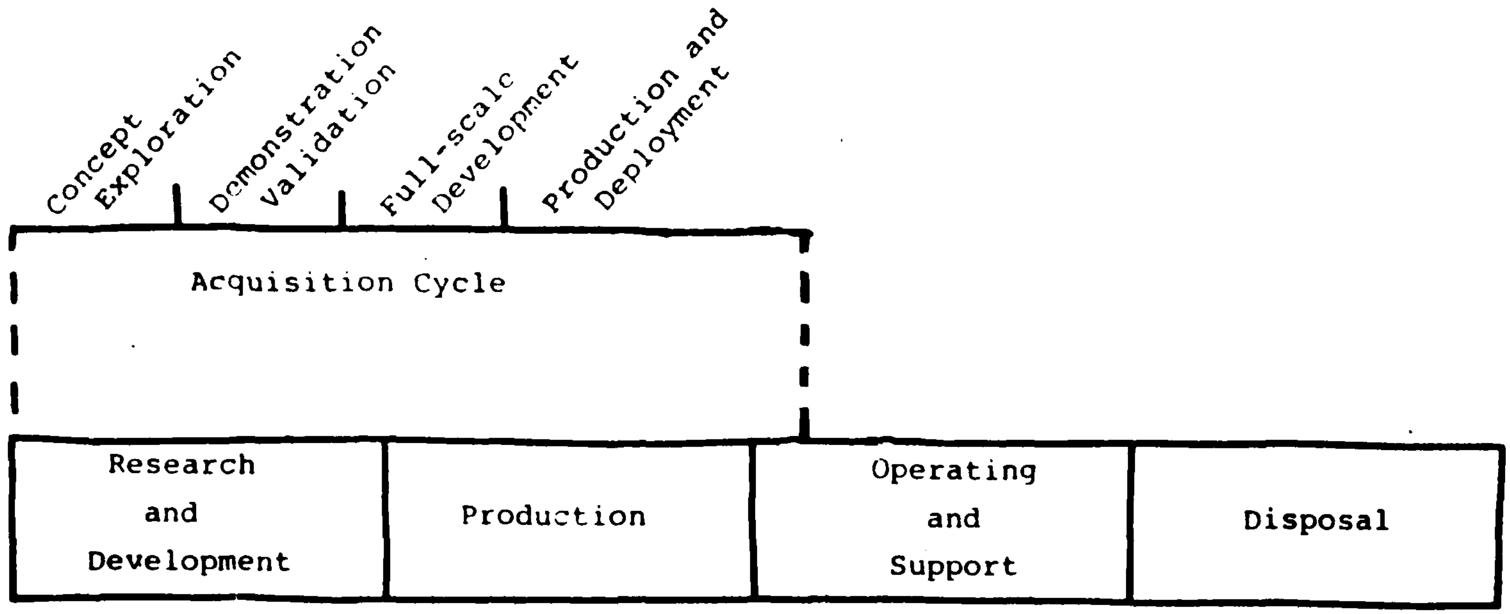


Figure 2.1. System Life Cycle Diagram

by HQ USAF or a major command (24:3.1). The concept exploration or conceptual phase is primarily concerned with substantiating the need, verifying capabilities and weighing possible alternatives. The end product of this phase is:

> the data which, in the form of studies, analyses, test results and conceptual drawings and specifications, demonstrates that concepts exist which have a high probability of satisfying the mission at an affordable cost in a reasonable time [24:3.8].

Usually these outputs are developed by private firms under contract to the government. Successful completion of the conceptual phase starts the demonstration and validation phase (20:7).

2. Demonstration and Validation Phase: During the Demonstration and Validation phase, prototypes are designed, built and tested; program characteristics such as performance, cost and schedule are developed (1:6). If resources are sufficient, two or more contracts may be awarded for firms pursuing different concepts (24:3.9). Reducing technical, cost and schedule risks are the major objectives of this phase (24:3.9). By the end of this phase, a concept is selected, its operational need is verified and the process moves into full scale development.

3. Full Scale Development: During the Full Scale Development phase, the weapon system and the major subsystems are designed, fabricated, tested and evaluated. The

purpose is to come up with a prototype that closely resembles the final weapon system (17:21). Much emphasis is placed on reducing the technical risks and developing a product that will meet the stated requirements.

4. Production and Initial Deployment: The production phase begins when the full scale development has demonstrated that the weapon system is ready for production. The system is produced and procured and support and training requirements are made available to facilitate deployment. Initial spare parts and most ancillary equipment are procured at this stage. A system is considered deployed when it is turned over to the using command (3:6). The point where Air Force Systems Command (AFSC) hands over the program to Air Force Logistics Command (AFLC) is known as Program Management Responsibility Transfer (PMRT). PMRT marks the end of the acquisition cycle and the beginning of the longest phase of a weapon system's life cycle (20:7). This phase is the ownership phase, also known as the operating and support phase (20:7). For jet engines, this time period generally lasts over 15 years.

Cost Considerations

Before the idea of life cycle costing was fully accepted, system performance was often the only criterion considered in system design (1:10). Little or no consideration was given to the operating and support costs that would occur after deployment (3:3-5). Any cost consideration was

secondary to technological capability: things like speed, firepower, payload and other performance related factors took precedence over any cost considerations (1:10). Exclusive emphasis on performance often resulted in performance exceeding the requirements at the cost of sacrifice in reliability, a factor that contributed to the rapid escalation of O&S costs (20:18).

With time, awareness grew that O&S cost was a rather sizable proportion of a weapon's LCC and as such it required greater management attention. Procurement, RDT&E and other initial costs were found to represent only the proverbial tip of the iceberg. By some estimates, O&S costs are a full half of the total cost of the weapon system (22:1). O&S costs range from 10 percent for some electronic systems to an average of about 50 percent of LCC for aircraft (14:3). In a Rand report of March 1977, author J. R. Nelson stated that depot repair and overhaul costs alone can exceed procurement costs of a new jet engine over a 15 year life span (18:V).

These kinds of findings necessitate that one consider the LCC ramifications of buying a weapon system and not just the initial costs. A procurement process that places the emphasis on lowest bid price or highest technical performance may cause the government to incur a higher life cycle cost because operation and support costs were neglected. The objective of life cycle costing is to meet the

operational needs while achieving the optimum balance of performance, reliability, schedule and cost (14:3).

The military has come to realize that not only should life cycle costing be done in connection with acquisition but that it should be done early in the acquisition cycle because decisions concerning design greatly affect O&S costs (25:224). The idea of doing life cycle costing during the early stages of the acquisition cycle is absolutely necessary because majority of the LCC is already determined by the decisions that are made during the early phases. Figure 2.2 shows that up to 95 percent of life cycle costs are affected by the end of full scale development.

Life Cycle Cost--Definition and Background

Definition: A typical definition of LCC is provided by Mr. Robert Seldon in his book on the same subject:

> The life cycle cost of an item--its total cost at the end of its lifetime--includes all expenses for research and development, production, modification, transportation, introduction of the item into inventory, new facilities, operation, support, maintenance, disposal, and any other costs of ownership, less any revenue at the end of its lifetime [25:9].

History (41:1-1 to 1-10): The Logistics Management Institute (LMI) conducted the early studies in the area of life cycle costing. The LMI report, issued in 1965 and titled "Life Cycle Costing in Equipment Repair," concluded that O&S costs and purchase prices could vary significantly

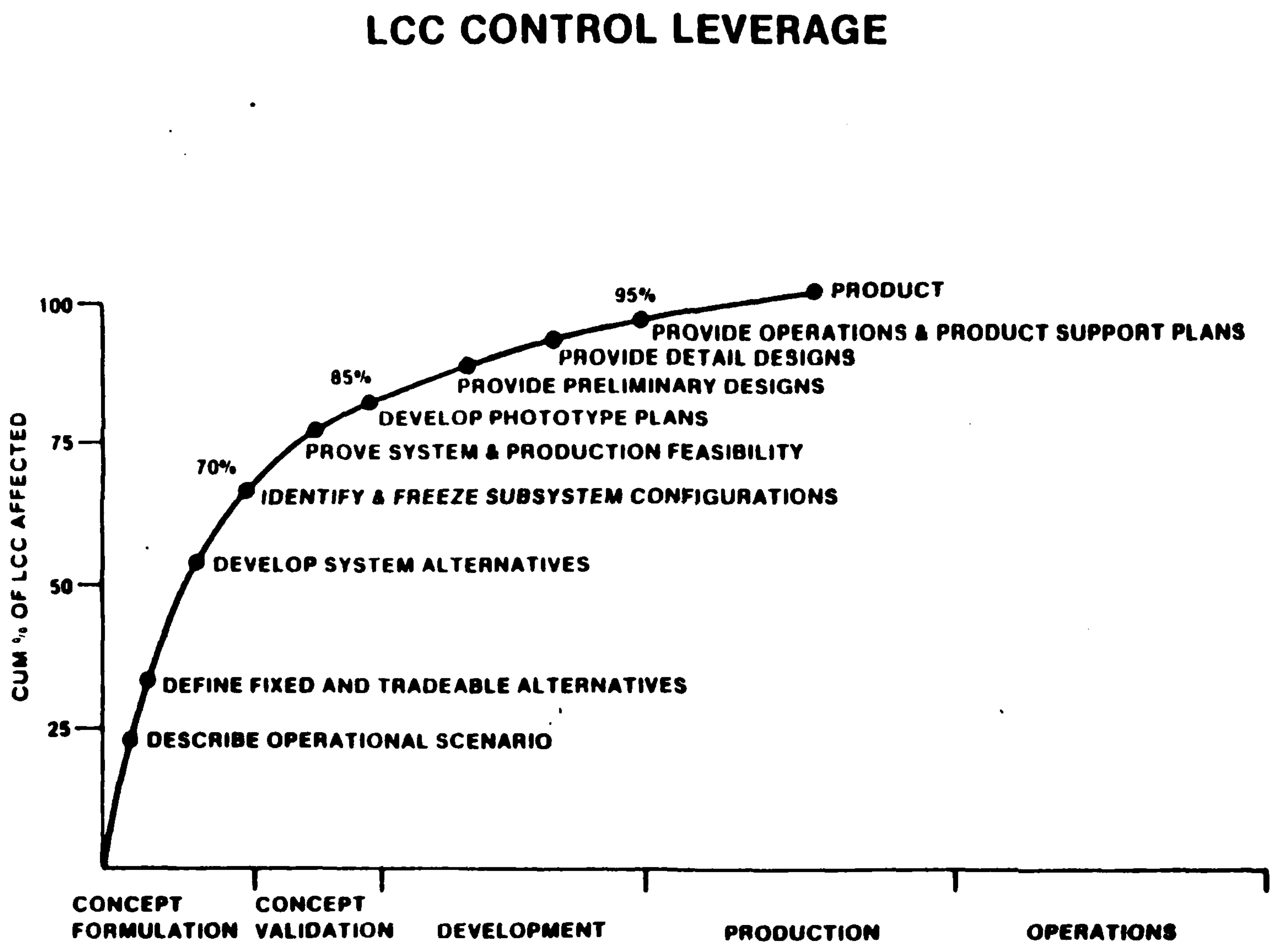


Figure 2.2. LCC Cycle Control Leverage

among different manufacturer's products. The report further stated that the use of predicted O&S costs is preferable to the traditional practice of ignoring them on the grounds that these predictions are uncertain. Based on these conclusions, the Assistant Secretary of Defense for Installation and Logistics (I&L), started trial procurements of certain items on a life cycle cost basis. Simultaneous to this event was the push for reduction of support costs. DoD directive 4100.35, issued in 1964, advocated minimization of the total life cycle cost of a system by employing the concept of Integrated Logistics Support.

In the late sixties, the growing public unwillingness to support growth in the defense budget resulted in several studies such as the Blue Ribbon Committee study and the Congressional Commission on Government Procurement study, among others. Common among the recommendations of these studies was that life cycle costing be applied to equipment and system acquisitions.

The seventies saw the issuance of several government regulations, directives and guidelines concerning LCC. Perhaps the most notable example is OMB circular A-109 which came out in April of 1976 and made the use of life cycle costing mandatory in the acquisition of major weapon systems.

Resistance To Life Cycle Costing

Today, life cycle costing is required for the almost all major system acquisition. However, the implementation of life cycle costing has been sporadic. In the 82-83 winter quarter issue of AFIT AOG quarterly, Margaret A. Emmelhainz reported that while current military directives require that life cycle costs be considered in all acquisition decisions, the implementation of this policy has tended to focus on controlling acquisition costs rather than life cycle costs (12:8). The reasons, she went on to say, are funding constraints in the early years of the program, the inability to easily and accurately estimate operation and support costs and schedule considerations. These factors have hindered Air Force efforts to structure contracts that emphasize life cycle costs (12:8).

In his book, Life Cycle Costing: A Better Method of Government Procurement, Mr. Robert Seldon discusses five factors that further help explain the early resistance to life cycle costing (25:4-7):

1. Separate Appropriations--Appropriation of procurement funds is separate from appropriations for operating and maintaining (O&M) funds. By specifying the use of appropriated funds, the original intent of congress was to designate and control expenditures. Doing this, however, also separated the responsibility of the management of these different funds. As a result there is no institutional

incentive for the procurement funds manager to pay more now so that O&S costs can be saved later. Seldon wrote that Congress had begun to show flexibility in the area as it developed a greater appreciation for the issue (25:4-5).

2. <u>Front End Loading</u>--Mr. Seldon commented that LCC ran into political objections. The idea of higher initial costs in research, development and production in order to achieve later economies in operation and maintenance was politically not welcomed. This was so because politicians were influenced much more strongly by immediate budget stringencies than by projected savings in the future. The concern for politicians was that the public will judge them and the administration on current performance and not on possible future benefits. Seldon noted, however, that when scenarios were clearly presented, congress had often chosen lower total cost and not lower immediate cost (25:5).

3. <u>Past Procurement Policies that Resembled LCC</u>--Mr. Seldon cites examples of the C-5A transport aircraft, the short range air-launched missile (SRAM), the Cheyenne helicopter and the F-14 fighter plane. These were part of the "total package procurements" instituted during the sixties under the guidance of the then Secretary of Defense Robert S. McNamara. Total package procurement was an attempt to contract for the total cost of development and production early in the development cycle. These programs incurred heavy cost over-runs and were criticized widely.

Even though total package procurement did not concern itself with O&S costs, its perceived resemblance to life cycle costing caused skepticism about LCC (25:6).

4. Reluctance of Contractors--A significant percentage of a system's O&S costs are predestined by the decisions made during the design of the system. In order to get contractors to pay attention to the life cycle cost implications of their design decisions, some link must be created between a system's O&S cost and the contractor's compensation. Since actual O&S costs may not be known for many years, rewards or penalties must be based on estimated costs. However, many military contractors are skeptical about any cost estimate that stretches fifteen to twenty years out in the future. Furthermore, there are many factors that can influence O&S costs that are outside the control of the contractor. Consequently, contractors are not too enthusiastic about committing themselves to a target cost that they may miss entirely for unforeseeable reasons (25:8).

5. Accuracy and Reliability of Data and LCC Methodology--O&S costs typically include a wide variety of activities performed by many different organizations in multiple geographic locations. Consequently, the task of collecting O&S cost data is a formidable one. It is almost impossible to compile a complete and accurate picture of the true O&S costs for a given system. One of the problems that can be

attributed partly to the lack of good data is the absence of a common methodology for estimating O&S costs. Mr. Seldon concluded:

> Even within DoD it is hard to obtain cost data for past DoD procurements because of intra-organizational factionalism, fear of criticism, simple bureaucratic confusion, or the inherent complexity of multimillion dollar contracts spread over many years with changing requirements. Also, cost-estimating methods vary widely among analysts; there are no commonly accepted costing models (25:8).

However, he also noted that the situation is improving and solutions to many of the problems are slowly evolving over time.

Life Cycle Cost Models

The literature review on the subject of LCC included an examination of some life cycle cost models. Some of these models are discussed below:

LSC model: The Air Force Logistics Command (AFLC) logistics Support Cost (LSC) model is an accounting type of cost model that is used to estimate support costs expected to be incurred by adopting a particular design for a weapon system. The model claims to be particularly useful in comparing and discriminating among design alternatives where relative cost difference is what is desired (7:4). The model has been in existence since the early 70s. In 1974, the team of Dover and Oswald reviewed this model as part of their MS thesis at the Air Force Institute of Technology.

The model then had 88 data elements and 10 equations (9:20). Over the years, the model has been slightly modified, mostly to incorporate costing of software. It now has 109 data elements and 11 equations. Each equation represents a cost of resources necessary to operate the logistics system (7:Appendix 3):

1. Cost of first line unit (FLU) repairs
2. On equipment maintenance costs
3. Off-equipment maintenance costs
4. Inventory management cost
5. Cost of support equipment
6. Cost of personnel training
7. Cost of management and technical data
8. Facilities Costs
9. Cost of fuel consumption
10. Cost of spare engines
11. Software support cost

The model is exercised by summing the costs mentioned above. Each equation has a large number of input variables. This model is intended for application in three different areas:

1. To obtain an estimate of the different logistics support costs between the proposed design configuration of two or more contractors during source selection.

2. To establish a baseline for contractual commitments on certain aspects of operational supportability which will be subject to verification.

3. To use as a decision aid in discriminating among design alternatives during prototyping or full-scale development (7:4).

The Super Operating and Support Cost Model (SOSCM): SOSCM is intended to determine initial and recurring support cost for jet engines. The model was developed by the Jet Engine Systems Programming Office of the Aeronautical Systems Division, USAF, to allow consistent evaluations of engine offerings between different engine manufacturers. The input data to this model falls into three categories:

1. Yearly Input: This input consists of annual engine flight hour (EFH) build-up and the annual quantity of spare engines and cost of support equipment. A maximum of 40 years of data may be input including the fleet build-up and life cycle support period.

2. Ground rule input: This category of data includes repair cycle times, order and ship time, shipping cost per pound, labor rate and fuel consumption.

3. Reliability and maintenance and cost input by engine component: This category contains unscheduled and scheduled failure data for mode line items (8:3).

The number of data elements in the SOSCM model exceed 200. Efforts have also been made to estimate jet engine O&S costs through the use of Cost Estimating Relationships. Two such efforts are discussed below:

1. Rand Study: In a RAND corporation executive summary titled " Life-Cycle Analysis of Aircraft Turbine Engines," author J. R. Nelson discussed several CERs that computed sub-categories of LCC of jet engines. As an

example, the RAND CER for estimating "base maintenance cost per engine flying hour consumed ($/BMCEFCHC)" is as follows:

$$\ln(\text{BMCEFHC}) = 3.50819 - 0.47457 \ln(\text{MTBO}) + 0.01299\ \text{OPSPAN} + 0.56739 \ln(\text{CPUSP})$$

Where

BMCEFHC	=	base maintenance cost per engine flying hour consumed
MTBO	=	maximum time between overhaul in hours
OPSPAN	=	time since operational use began in quarters
CPUSP	=	Current unit production selling price

Nelson presented several other CERs that computed portions of LCC. Some of these categories included development cost, component improvement cost, and depot maintenance cost per engine flying hour. No more than six variables were used in any one particular CER (18:25).

2. Cox Model: In a 1985 master's thesis at the Air Force Institute of Technology, the author Brenda Cox developed the following CER for estimating partial jet engine O&S costs (24:58):

$$\text{ADJC} = -415350 + 184.307\ \text{TIT} + 93565.729\ \text{SFC} + 18.962133\ \text{WT} + 0.049260\ \text{EFHRS}$$

Where,

ADJC = Adjusted O&S cost

TIT = turbine inlet temperature

SFC = specific fuel consumption

WT = weight of the engine

EFHRS = annual engine flying hours

The literature review of O&S cost models showed that accounting type of cost models such as the LSC model or the SOSCM model are basically very large models that require voluminous amounts of data input. In contrast, CERs are rather compact models that use statistical techniques to estimate similar costs while employing the use of a few selected variables.

III. Model-A

Introduction

Model-A is an accounting type of cost model that estimates annual recurring costs associated with the repair and maintenance of a jet engine. The costs involved in this model can be put into three broad categories:

1. Costs to Perform Maintenance Directly on the Engine

   1a. Labor costs associated with maintenance actions

   1b. Cost of fuel to do engine trims and checks

2. Cost of Repairs

   2a. Annual repair cost at base level

   2b. Annual repair cost at depot level

3. Cost of Spares

   3a. Cost of expendables associated with maintenance of the engine

   3b. Cost of expendables associated with repair actions

   3c. Cost of replacing condemned parts

Mean Time Between Failure

Through out the model, the word "failure" refers to the failure of the part that necessitates the removal of the engine from the aircraft. To use a very simplified example, if there are three such parts and their respective mean time between failures (MTBF) are 100 hours, 150 hours and 200

hours, then the maximum value that MTBF can take, as used in this model, is 100 hours. This is so because, starting from zero hour, the first failure would normally be expected around 100 hours which is the MTBF for part one. When part one fails, it will be either repaired or replaced. If nothing is done to the other two parts at this point, then the next failure would normally occur approximately 50 hours from this point or 150 hours from zero hour. Similarly part three would fail approximately 50 hours hence or 200 hours from zero hour. Under this kind of a scenario, one would experience three failures in 200 hours and the aggregrate MTBF would be 66.66 hours (200 divided by three).

If on the other hand, when the first part failed, maintenance was accomplished so that the other two parts were restored to zero hour also, then the next failure would occur about 100 hours from that point (the MTBF of part one). Under this scenario, part one would fail approximately every 100 hours and the other parts would be restored at the same time so that the aggregrate MTBF would never exceed approximately 100 operating hours.

Categories of Parts

All repairable parts have been placed in one of three categories. Every part in each category is treated as though it has the same MTBF, the same cost to repair, and the same cost to replace. Category L consists of all the parts that have a low MTBF. These parts are also the least

expensive to repair and replace. Category H consists of all the parts that have a high MTBF. These parts are also the most expensive to repair and replace. Category M consists of those parts whose MTBF, cost to repair, and cost to replace are between the two extremes.

Scheduled Maintenance Actions

Maintenance actions are scheduled at fixed intervals of operating hours. The interval of time between one scheduled maintenance action and the next one is the scheduled maintenance interval (SMI). The total number of scheduled maintenance actions per year is a function of total operating hours (annual flying hours) and SMI:

$$TSMA = AFH/SMI \tag{1}$$

Where

TSMA = the total number of scheduled maintenance actions per year

AFH = total number of flying hours per engine

SMI = scheduled maintenance interval

For example, if the annual flying hours per engine equal 10,000 hours and there is maintenance action scheduled every 900 hours (SMI = 900), then the total number of scheduled maintenance actions would be a little over eleven as shown below:

$$TSMA = AFH/SMI = 10{,}000/900 \cong 11$$

The Probability of Failure

"P" is designated as the probability of a failure before a scheduled maintenance action (SMA). This probability is a function of MTBF and SMI. Theoretically, if one kept reducing SMI, that is if one scheduled maintenance at shorter and shorter intervals, one could almost guarantee no failure. The time between failure (TBF) is assumed to be exponentially distributed. This assumption stems from the fact that the number of failures in a given time interval follows a Poisson distribution. TBF, should then follow an exponential distribution. Therefore, in order to calculate the probability of a failure before a scheduled maintenance action, one must calculate the shaded area in Figure 3.1 presented below.

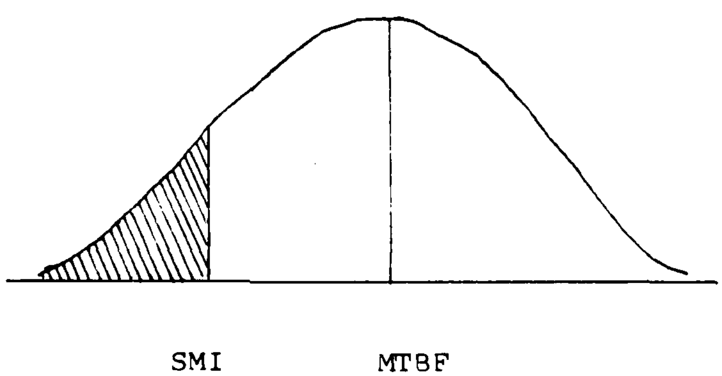


Figure 3.1. An Exponential Distribution Whose Mean Is MTBF

Figure 3.1 represents an exponential distribution whose mean is MTBF. The shaded area represents the probability of a failure between zero hour and the SMI. The shaded area can be calculated by the following formula (15:199):

$$P = \int_{0}^{SMI} \lambda e^{-\lambda t} dt$$

Where

P = the probability of a failure before a SMA (between zero hour and SMI)

λ = the reciprocal of MTBF = 1/MTBF

e = the exponential constant, 2.718281828.....

t = engine operating time in hours

Taking the integral of this formula from zero time to SMI should determine the probability of failure before SMI.

$$\int_{0}^{SMI} \lambda e^{-\lambda t} dt = 1 - e^{-\lambda SMI}$$

Since λ is = 1/MTBF, the Eq above transforms to

$$1 - e^{-SMI/MTBF}$$

therefore,

$$P = 1 - e^{-SMI/MTBF} \qquad (2)$$

For example, if MTBF equaled 900 hours and SMI was equal to 600 hours, the probability of a failure before a scheduled maintenance action would be:

$$P = 1 - e^{-600/900}$$

$$P = 0.4865$$

Following this procedure, one can determine the probability of a failure before a scheduled maintenance action. The probability of failure of a category L part before a SMA can be represented as:

$$PL = 1 - e^{-SMI/MTBFL} \tag{3}$$

where PL is the probability of failure of a category L part before a SMA and MTBFL is the MTBF of category L parts. The probably of failure associated with the other two categories can be similarly calculated.

$$PM = 1 - e^{-SMI/MTBFM} \tag{4}$$

and

$$PH = 1 - e^{-SMI/MTBFH} \tag{5}$$

Where PM and PH are the probabilities of failure before a SMA associated with categories M and H, respectively. MTBFM and MTBFH are the respective mean time between failures.

Unscheduled Maintenance Actions

Each failure necessitates a maintenance action. The number of these maintenance actions can be estimated since the probabilities of failures are known. For example, if the probability of a failure before a SMA is 0.2 and there are 10 scheduled maintenance actions (TSMA) for the year, one could speculate that there will be two failures (10 x 0.2) during that year and therefore, two unscheduled maintenance actions. The number of unscheduled maintenance actions associated with each category are calculated below:

$$\text{TUMAL} = \text{PL} \times \text{TSMA} \tag{6}$$

$$\text{TUMAM} = \text{PM} \times \text{TSMA} \tag{7}$$

$$\text{TUMAH} = \text{PH} \times \text{TSMA} \tag{8}$$

where

TUMAL = Total number of unscheduled maintenance actions per year caused by failures of category L parts

TUMAM = Total number of unscheduled maintenance actions per year caused by failures of category M parts

TUMAH = Total number of unscheduled maintenance actions per year caused by failures of category H parts

The total number of unscheduled maintenance actions during the year then is simply the sum of these three.

$$\text{TUMA} = \text{TUMAL} + \text{TUMAM} + \text{TUMAH} \tag{9}$$

Where,

TUMA = the total number of unscheduled maintenance actions per year

Next, the total number of maintenance actions, scheduled and unscheduled, can be calculated:

$$NMA = TSMA + TUMA \quad (10)$$

Where

NMA = total number of maintenance actions per year; it is simply the sum of the number of scheduled maintenance actions per year (TSMA) and the number of unscheduled maintenance (TUMA) actions per year

1. Costs to Perform Maintenance Directly on the Engine

As stated in the beginning of this chapter, this category of costs is further divided into: (1) labor costs associated with maintenance actions, and (2) cost of fuel to do engine trims and checks.

1a. Labor Costs Associated with Maintenance Actions (TMALC)

$$TMALC = [(MHMA \times NMA) + (TSMA \times MHSMA) + (TUMA \times MHUMA)] \times CMH \quad (11)$$

Where

MHMA = Manhours to do those maintenance activities that are common to both scheduled and unscheduled maintenance actions

MHMA = MHRE + MHIE + MHTE + MHTB

MHRE = Manhours needed to remove an engine, this includes transportation to the repair facility

MHIE = Manhours needed to install an engine, this includes transportation back to the aircraft

MHTE = Manhours needed to trim an engine

MHTB = Manhours needed to do test the engine

NMA = annual number of maintenance actions

TSMA = annual number of scheduled maintenance actions

TUMA = annual number of unscheduled maintenance actions

MHSMA = Average number of manhours needed to perform "hands on" maintenance for a scheduled maintenance action

MHUMA = Average number of manhours needed to perform "hands on" maintenance for an unscheduled maintenance action

CMH = Average cost per manhour for personnel directly involved in maintenance/repair activity of jet engines; this cost represents not just an hourly wage rate but also an allocated overhead cost

Each maintenance action, whether it be scheduled or unscheduled, involves some common maintenance activities. This is represented by the term MHMA which has four components as described. However, there is a difference between scheduled and unscheduled maintenance actions when it comes to actual "hands on" maintenance. This is because while scheduled maintenance is routine and standard procedures are followed, each unscheduled maintenance is in

response to a problem or failure of some kind and would normally require a different kind of maintenance attention.

Eq 11 takes the total annual number of maintenance actions, scheduled and unscheduled, and multiplies it by the manhours required to do the common maintenance activities (MHMA). Further, the total number of scheduled maintenance actions is multiplied by the manhours it takes to perform "hands on" maintenance for every scheduled maintenance action (MHSMA). Similarly, the total annual number of unscheduled maintenance actions is multiplied by the number of manhours it takes to perform "hands on" maintenance for each unscheduled maintenance action. The sum of these three products represents the total annual manhours associated with maintenance. Multiplying this sum by the average cost of manhour (CMH) yields the total annual maintenance associated labor cost.

1b. Cost of Fuel to Do Engine Trims and Checks

The following equation calculates the annual cost of fuel to trim a jet engine and also to test it after it has received maintenance action:

$$COSTFU = [NMA \times (FUELTP + FUELTC)] \times FUEL \qquad (12)$$

Where

COSTFU = the annual cost of fuel to trim a jet engine and also to test it after it has received maintenance action

FUELTP = average number of gallons of fuel required to trim the engine while removed from the aircraft

FUELTC = average number of gallons of fuel required to test the engine after repair

FUEL = cost of fuel per gallon

Each maintenance action, scheduled or unscheduled, takes the same amount of fuel to trim and test an engine. This amount is represented by the expression "(FUELTP + FUELTC)." Multiplying this number by the annual number of maintenance actions (NMA) yields the total annual volume of fuel used to trim and test an engine. Multiplying the volume of fuel by the cost of fuel fields the annual cost of fuel (COSTFU).

2. Cost of Repairs

This category of costs is further broken down into two parts: (1) Repair cost at base level, and (2) repair cost at depot level.

2a. Base Repair Total Cost (BRTC)

Base repair total cost represents the annual base level repair cost of parts removed from one engine. Eqs 13, 14, and 15 calculate this cost. Eq 13 calculates the base level repair costs stemming from scheduled maintenance actions; Eq 14 calculates base level repair costs arising from unscheduled maintenance actions and Eq 15 simply sums these two costs to come up with the total annual base repair cost.

2a.1. Base Repair Cost Due To Scheduled Maintenance Action (BRTCS)

$$BRTCS = TSMA \times [(QPESL \times RTSL \times BURCL) + (QPESM \times RTSM \times BURCM) + (QPESH \times RTSH \times BURCH)] \quad (13)$$

where

BRTCS = Annual base repair cost due to scheduled maintenance actions

TSMA = Annual number of scheduled maintenance actions

QPESL = Average number of category L parts removed for repair during a scheduled maintenance action

QPESM = Average number of category M parts removed for repair during a scheduled maintenance action

QPESH = Average number of category H parts removed for repair during a scheduled maintenance action

RTSL = That percent of parts removed from category L that is repaired at base level

RTSM = That percent of parts removed from category M that is repaired at base level

RTSH = That percent of parts removed from category H that is repaired at base level

BURCL = Average base unit repair cost of a category L part

BURCM = Average base unit repair cost of a category M part

BURCH = Average base unit repair cost of a category H part

The unit repair cost of any category of parts reflects the labor cost as well as an allocated overhead cost. The term "(QPESL x RTSL x BURCL)" represents the average cost of repair, per each scheduled maintenance action, of parts from category L. Likewise, "(QPESM x RTSM x BURCM) and (QPESH x RTSH x BURCH)" are identical formulations which refer to average costs of repair, per scheduled maintenance action, of parts from categories M and H, respectively. The sum of these three elements of the equation,

"[(QPESL x RTSL x BURCL) + (QPESM x RTSM x BURCM)
+ (QPESH x RTSH x BURCH)]"

represents total base repair cost per scheduled maintenance action. Multiplying this quantity by the total number of scheduled maintenance actions per year (TSMA) yields the total annual base level repair cost due to scheduled maintenance actions (BRTCS).

2a.2. <u>Base Repair Total Cost due to Unscheduled Maintenance (BRTCU)</u>

Eq 14 calculates the annual base level repair cost due to unscheduled maintenance actions:

BRTCU = {TUMAL x [(QPEUL x RTSL x BURCL)
+ (QPESM x RTSM BURCM)
+ (QPESH x RTSH x BURCH)]}
+ {TUMAM x [(QPESL x RTSL x BURCL)
+ (QPEUM x RTSM x BURCM)

$$+ (QPESH \times RTSH \times BURCH)]\}$$

$$+ \{TUMAH \times [(QPESL \times RTSL \times BURCL)$$

$$+ (QPESM \times RTSM \times BURCM)$$

$$+ (QPEUH \times RTSH \times BURCH)]\} \qquad (14)$$

where,

BRTCU = Annual base repair cost of unscheduled maintenance actions

TUMAL = Annual number of unscheduled maintenance actions caused by problems with category L parts

QPEUL = Average number of category L parts removed for repair during an unscheduled maintenance action which was caused by category L part(s)

QPEUM = Average number of category M parts removed for repair during an unscheduled maintenance action which was caused by category M part(s)

QPEUH = Average number of category H parts removed for repair during an unscheduled maintenance action which was caused by category H part(s)

TUMAM = Annual number of unscheduled maintenance actions caused by problems with category M parts

TUMAH = Annual number of unscheduled maintenance actions caused by problems with category H parts

In comparison to Eq 13, Eq 14 is much longer. This is so because unscheduled maintenance actions require removal of a different number of parts from that category that caused the unscheduled maintenance. For example, if unscheduled maintenance had to be accomplished due to a problem with a category L part, the number of category L parts removed will be different than if it were a scheduled

maintenance (QPEUL as opposed to QPESL). The other two categories (in this case, categories M and H), will be treated as if it were a scheduled maintenance action. So, during a category L related unscheduled maintenance, QPESM and QPESH are the respective numbers of parts from categories M and H respectively, the same amount that is removed for scheduled maintenance actions. The underlined part of Eq 14 (presented again below) reflects this.

$$
\begin{aligned}
\mathrm{BRTCU} = {} & [\mathrm{TUMAL} \times [(\mathrm{QPEUL} \times \mathrm{RTSL} \times \mathrm{BURCL}) \\
& + (\mathrm{QPESM} \times \mathrm{RTSM} \times \mathrm{BURCM}) \\
& + (\mathrm{QPESH} \times \mathrm{RTSH} \times \mathrm{BURCH})]] \\
& + [\mathrm{TUMAM} \times [(\mathrm{QPESL} \times \mathrm{RTSL} \times \mathrm{BURCL}) \\
& + (\mathrm{QPEUM} \times \mathrm{RTSM} \times \mathrm{BURCM}) \\
& + (\mathrm{QPESH} \times \mathrm{RTSH} \times \mathrm{BUTCT})]] \\
& + [\mathrm{TUMAH} \times [(\mathrm{QPESL} \times \mathrm{RTSL} \times \mathrm{BURCL}) \\
& + (\mathrm{QPESM} \times \mathrm{RTSM} \times \mathrm{BURCM}) \\
& + (\mathrm{QPEUH} \times \mathrm{RTSH} \times \mathrm{BURCH})]] \qquad (14)
\end{aligned}
$$

The other two elements of Eq 14 follow the same logic with categories M and H related unscheduled maintenance actions.

The sum of base repair costs due to scheduled maintenance actions plus base repair costs due to unscheduled maintenance actions equal Eq 15.

BRTC = Annual base level repair cost due to scheduled maintenance actions + annual base level repair costs due to unscheduled maintenance actions

$$BRTC = BRTCS + BRTCU \quad (15)$$

2b. Annual Repair Cost at Depot Level (DRTC)

Depot repair costs are estimated in approximately the same manner as the base repair costs. Following is the formula for depot repair total costs arising out of scheduled maintenance actions (DRTCS):

2b.1. Depot Level Repair Cost Due to Scheduled Maintenance Actions (DRTCS)

$$\begin{aligned} DRTCS = \; & TSMA \times \{[QPESL \times NRTSL \times (1-DCONDL) \times DURCL] \\ & + [QPESM \times NRTSM \times (1-DCONDM) \times DURCM] \\ & + [QPESH \times NRTSH \times (1-DCONDH) \times DURCH]\} \end{aligned} \quad (16)$$

Where

DRTCS = Annual depot repair cost of scheduled maintenance actions

NRTSL = That percent of "removed category L parts" that is sent to depot for repair

NRTSM = That percent of "removed category M parts" that is sent to depot for repair

NRTSH = That percent of "removed category H parts" that is sent to depot for repair

DCONDL = That percent of NRTSL that is condemned at depot level

DCONDM = That percent of NRTSM that is condemned at depot level

DCONDH = That percent of NRTSH that is condemned at depot level

DURCL = Depot unit repair cost of a category L part

DURCM = Depot unit repair cost of a category M part

DURCH = Depot unit repair cost of a category H part

Once again, unit repair cost reflects labor cost and allocated overhead cost. Eq 16 is almost identical to Eq 13. Putting them together will illustrate this:

$$\begin{aligned} BRTCS = \; & TSMA \times [(QPESL \times RTSL \times BURCL) \\ & + (QPESM \times RTSM \times BURCM) \\ & + (QPESH \times RTSH \times BURCH)] \end{aligned} \tag{13}$$

$$\begin{aligned} DRTCS = \; & TSMA \times \{[QPESL \times NRTSL \times (1-DCONDL) \times DURCL] \\ & + [QPESM \times NRTSM \times (1-DCONDM) \times DURCM] \\ & + [QPESH \times NRTSH \times (1-DCONDH) \times DURCH]\} \end{aligned} \tag{16}$$

In Eq 13, the number of parts removed for repair (QPESL, QPESM, QPESH), were multiplied by the percent that are repaired at base level (RTSL, RTSM, RTSH). Eq 16 replaces the base repair rates in Eq 13 by the depot repair rates. The percent of parts repaired at the depot level is calculated by terms such as NRTSL x (1-DCONDL). This is because NRTSL represents that percent of QPESL that is sent to the depot for repair. However, a ceratin percent of NRTSL, on the average, is condemned at the depot (DCONDL). Therefore, the effective repair rate at the depot is "NRTSL x (1-DCONDL)" for category L parts. For category M parts, the equivalent expression would be "NRTSM x (1-DCONDM)."

2b.2. Depot Level Repair Cost Due To Unscheduled Maintenance Actions (DRTCU)

$$
\begin{aligned}
DRTCU = &\{TUMAL \times [QPEUL \times NRTSL \times (1-DCONDL) \times DURCL] \\
&+ [QPESM \times NRTSM \times (1-DCONDM) \times DURCM] \\
&+ [QPESH \times NRTSH \times (1-DCONDH) \times DURCH]\} \\
&+ \{TUMAM \times [QPESL \times NRTSL \times (1-DCONDL) \times DURCL] \\
&+ [QPEUM \times NRTSM \times (1-DCONDM) \times DURCM] \\
&+ [QPESH \times NRTSH \times (1-DCONDH) \times DURCH]\} \\
&+ \{TUMAH \times [QPESL \times NRTSL \times (1-DCONDL) \times DURCL] \\
&+ [QPESM \times NRTSM \times (1-DCONDM) \times DURCM] \\
&+ [QPEUH \times NRTSH \times (1-DCONDH) \times DURCH]\}
\end{aligned} \tag{17}
$$

All the variables in this equation have been defined earlier. Eq 17 is simply an extension of Eq 16. Annual number of scheduled maintenance actions (TSMA) is now replaced by the three different kinds of unscheduled maintenance actions: TUMAL, TUMAM AND TUMAH (total number of unscheduled maintenance actions per year caused by problems with parts from categories L, M and H, respectively). Eq 17 is very similar to Eq 14 which calculated base repair total cost arising from unscheduled maintenance actions. Once again, since one is now dealing with depot, terms like RTSL and BURCL are replaced with their depot counterparts like NRTSL, DCONDL, DURCL and the like.

Depot Repair Total Cost (DRTC)

DRTC = Depot repair cost arising from scheduled maintenance actions + depot repair cost arising from unscheduled maintenance actions;

$$DRTC = DRTCS + DRTCU \tag{18}$$

3. Cost of Spares

Since this model is only concerned with repair and maintenance costs, the pipeline spare costs are not included. Spares costs are divided into three categories:

3A. Cost of expendables associated with maintenance actions

3B. Cost of expendables associated with repair actions

3C. Cost of replacement of condemned parts

3A. Cost of Expendables Associated with Maintenance Actions (EXPM):

With every maintenance action, there is an expense associated with expendables. Expendables are items whose repair costs exceed their procurement cost; in other words it is cheaper to repalce them than to fix them. Normally these items are relatively inexpensive; however, cumulatively they may represent a significant cost. The next three equations calculate the cost of expendables. Once again, in keeping with the presentation format of the model, the cost of expendables is categorized by scheduled and unscheduled maintenance actions.

3a.1. Cost of Expendables Associated with Scheduled Maintenance Actions (EXPMS):

Eq 19 calculates the cost of expendables associated with scheduled maintenance actions

$$EXPMS = TSMA \times (EXPSL + EXPSM + EXPSH) \qquad (19)$$

Where

EXPSL = the average cost of expendables associated with category L parts with each scheduled maintenance action

EXPSM = the average cost of expendables associated with category M parts with each scheduled maintenance action

EXPSH = the average cost of expendables associated with category H parts with each scheduled maintenance action

The sum of EXPSL, EXPSM and EXPSH yields the total cost of expendables associated with one scheduled maintenance action. Multiplying that number by the total number of scheduled maintenance actions per year (TSMA) gives one the total annual cost of expendables associated with scheduled maintenance actions.

3a.2. Cost of Expendables Associated with Unscheduled Maintenance Actions (EXPMU)

$$\begin{aligned} EXPMU = {} & [TUMAL \times (EXPUL + EXPSM + EXPSH)] \\ & + [TUMAM \times (EXPSL + EXPUM + EXPSH)] \\ & + [TUMAH \times (EXPSL + EXPSM + EXPUH)] \qquad (20) \end{aligned}$$

Where

EXPUL = the average cost of expendables that can be attributed to category L during each unscheduled maintenance action which is caused by a problem with category L parts

EXPUM = the average cost of expendables that can be attributed to category M during each unscheduled maintenance action which is caused by a problem with category M parts

EXPUH = the average cost of expendables that can be attributed to category H during each unscheduled maintenance action which is caused by a problem with category H parts

In keeping with the idea that the maintenance on parts of the category which is causing the unscheduled maintenance, is different than the maintenance on the other two sections which are treated as if it were a scheduled maintenance action, the cost of expendables also differs only for that category during an unscheduled maintenance action. For example, if the unscheduled maintenance is being caused by problems with category L parts section, then the maintenance action will generate a different cost of expedables associated with category L (EXPUL and not EXPSL as would be the case for a scheduled maintenance action). The other two sections in this kind of an unscheduled maintenance action (one caused by a category L part) would generate EXPSM and EXPSH respectively just as they would in a scheduled maintenance action. As a result, the total cost of expendables associated with a category L related unscheduled maintenance action would be equal to the sum of EXPUL, EXPSM and EXPSH. Multiplying this sum by the total number of such unscheduled

maintenance actions (TUMAL) would yield the total annual cost of expendables associated with unscheduled maintenance actions caused by a problem with category L parts. This can be represented as:

$$TUMAL \times (EXPUL + EXPSM + EXPSH)$$

This notation is the underlined part of Eq 20 which is presented again below:

$$\begin{aligned} EXPMU = {} & [TUMAL \times (EXPUL + EXPSM + EXPSH)] \\ & + [TUMAM \times (EXPSL + EXPUM + EXPSH)] \\ & + [TUMAH \times (EXPSL + EXPSM + EXPUH)] \end{aligned} \tag{20}$$

The other two elements are created by unscheduled maintenance actions caused by problems with category M and category H respectively. The final output of Eq 20 is the total annual cost of expendables associated with unscheduled maintenance actions (EXPMU). Eq 19 had earlier yielded the total annual cost of expendables associated with scheduled maintenance actions (EXPMS). The sum of the two simply aggregates the total annual cost of expendables associated with maintenance actions (EXPM):

$$EXPM = EXPMS + EXPMU \tag{21}$$

3B. <u>Cost of Expendables Associated with Repair Actions (TEXPR)</u>

Like maintenance actions, repair actions also use up expendables. The total cost of expendables associated with repair actions (TEXPR) can be broken down in four parts: (1) at base level due to scheduled maintenance actions, (2) at depot level due to scheduled maintenance actions, (3) at base level due to unscheduled maintenance actions, and (4) at depot level due to unscheduled maintenance actions.

3b.1. <u>Total Annual Cost of Expendables Associated with Repair Actions at Base Level Due to Scheduled Maintenace Actions (TEXPRBS)</u>

$$\begin{aligned} TEXPRBS = TSMA \times [&(QPESL \times RTSL \times EXPRBL) \\ &+ (QPESM \times RTSM \times EXPRBM) \\ &+ (QPESH \times RTSH \times EXPRBH)] \end{aligned} \tag{22}$$

where the new terms are:

EXPRBL = the average cost of expendables associated with each base level repair action on a category L part

EXPRBM = the average cost of expendables associated with each base level repair action on a category part

EXPRBH = the average cost of expendables associated with each base level repair action on a category H part

During a scheduled maintenance action, the average number of parts removed for repair from the three categories are QPESL, QPESM, QPESH, respectively. QPESL for example is

the average number of parts removed for repair from category L. Multiplying this number by the average percent of these parts that is repaired at base level (RTSL), will yield the number of category L parts that on the average are repaired at base level with every scheduled maintenance action. Now, if "EXPRBL" is the cost of expendables associated with each repair action involving a category L part, then the cost of expendables associated with repair actions involving category L parts during a scheduled maintenance action at base level would be "QPESL x RTSL x EXPRBL." This is the underlined element in Eq 22. The other two elements of Eq 22 estimate the same cost for the other two categories. The sum of the three elements is multiplied by TSMA to calculate annual costs.

3b.2. Annual Depot Level Cost of Expendables Associated with Repair Actions Generated Due to Scheduled Maintenance Actions (TEXPRDS)

Eq 22 calculated the cost of expendables associated with scheduled maintenance actions at base level (TEXPRBS). Eq 23 calculates the same for depot level:

$$\begin{aligned} TEXPRDS = TSMA \times [&(QPESL \times NRTSL \times (1-DCONDL) \times EXPRDL) \\ &+ (QPESM \times NRTSM \times (1-DCONDM) \times EXPRDM) \\ &+ (QPESH \times NRTSH \times (1-DCONDH) \times EXPRDH)] \end{aligned} \tag{23}$$

Where the new terms are:

EXPRDL = the average cost of expendables associated with a depot level repair action on a category L part

EXPRDM = the average cost of expendables associated with a depot level repair action on a category M part

EXPRDH = the average cost of expendables associated with a depot level repair action on a category H part

The formulation is very similar to Eq 22; depot related terms have been substituted for base related terms. For example if QPESM is the average number of parts removed for repair from category M during a scheduled maintenance action and the number of parts repaired at base level in this kind of a scenario is QPESM x RTSM, then the depot level counterpart of this expression would be "QPESM x NRTSM x (1-DCONDM)."

3b.3. Annual Base Level Cost of Expendables Associated with Repair Actions Generated Due to Unscheduled Maintenance Actions (TEXPRBU)

$$\begin{aligned}
\text{TEXPRBU} = \{&\text{TUMAL} \times [(\text{QPEUL} \times \text{RTSL} \times \text{EXPRBL}) \\
&+ (\text{QPESM} \times \text{RTSM} \times \text{EXPRBM}) \\
&+ (\text{QPESH} \times \text{RTSH} \times \text{EXPRBH})]\} \\
&+ \{\text{TUMAM} \times [(\text{QPESL} \times \text{RTSL} \times \text{EXPRBL}) \\
&+ (\text{QPEUM} \times \text{RTSM} \times \text{EXPRBM}) \\
&+ (\text{QPEUH} \times \text{RTSH} \times \text{EXPRBH})]\} \\
&+ \{\text{TUMAH} \times [(\text{QPESL} \times \text{RTSL} \times \text{EXPRBL}) \\
&+ (\text{QPESM} \times \text{RTSM} \times \text{EXPRBM}) \\
&+ (\text{QPEUH} \times \text{RTSH} \times \text{EXPRBH})]\} \qquad (24)
\end{aligned}$$

All terms in Eq 24 have been defined previously. An unscheduled maintenance action caused by a problem with category L parts will generate the removal of parts that are QPEUL, QPESM and QPESH (had it been a scheduled maintenance action, the terms would have been QPESL, QPESM and QPESH). Multiplied by their respective base level repair rates (RTSL, RTSM and RTSH), and the respective costs of expendables (EXPRBL, EXPRBM and EXPRBH) yields a term like:

"(QPEUL x RTSL x EXPRBL) + (QPESM x RTSM x EXPRBM)
+ (QPESH x RTSH x EXPRBH)"

This term represents the cost of expendables associated with repair actions at base level due to one unscheduled maintenance action caused by problems with category L parts. Multiplying this number by the total annual number of unscheduled maintenance actions caused by problems with category L parts yields the total cost of expendables per year associated with repair actions that are generated by category L related unscheduled maintenance actions.

The remainder of Eq 24 deals with this kind of cost that stem from the other two causes of unscheduled maintenance actions, namely those caused by problems with category M parts and those caused by problems with category H parts.

3b.4. Annual Depot Level Cost of Expendables Associated with Repair Actions Generated by Unscheduled Maintenance Actions (TEXPRDU)

$$
\begin{aligned}
\mathrm{TEXPRDU} = \{&\mathrm{TUMAL} \times [(\mathrm{QPEUL} \times \mathrm{NRTSL} \times (1\text{-}\mathrm{DCONDL}) \times \mathrm{EXPRDL}) \\
&+ (\mathrm{QPESM} \times \mathrm{NRTSM} \times (1\text{-}\mathrm{DCONDM}) \times \mathrm{EXPRDM}) \\
&+ (\mathrm{QPESH} \times \mathrm{NRTSH} \times (1\text{-}\mathrm{DCONDH}) \times \mathrm{EXPRBH})]\} \\
&+ \{\mathrm{TUMAM} \times [(\mathrm{QPESL} \times \mathrm{NRTSL} \times (1\text{-}\mathrm{DCONDL}) \times \mathrm{EXPRDL}) \\
&+ (\mathrm{QPEUM} \times \mathrm{NRTSM} \times (1\text{-}\mathrm{DCONDM}) \times \mathrm{EXPRDM}) \\
&+ (\mathrm{QPESH} \times \mathrm{NRTSH} \times (1\text{-}\mathrm{DCONDH}) \times \mathrm{EXPRDH})]\} \\
&+ \{\mathrm{TUMAH} \times [(\mathrm{QPESL} \times \mathrm{NRTSL} \times (1\text{-}\mathrm{DCONDL}) \times \mathrm{EXPRDL}) \\
&+ (\mathrm{QPESM} \times \mathrm{NRTSM} \times (1\text{-}\mathrm{DCONDM}) \times \mathrm{EXPRDM}) \\
&+ (\mathrm{QPEUH} \times \mathrm{NRTSH} \times (1\text{-}\mathrm{DCONDH}) \times \mathrm{EXPRDH})]\} \qquad (25)
\end{aligned}
$$

Eq 25 is identical to to Eq 24 with one exception. Terms standing for repair rates at base level like RTSL, RTSM and RTSH in Eq 24 have been replaced by their depot counterparts like NRTSL x (1-DCONDL), NRTSM x (1-DCONDM) and NRTSH x (1-DCONDH).

Eqs 22, 23, 24 and 25 respectively calculated the annual costs of expendables associated with repair actions: (1) at base level due to scheduled maintenance actions, (2) at depot level due to scheduled maintenance actions, (3) at base level due to unscheduled maintenance actions, and (4) at depot level due to unscheduled maintenance actions. Adding these four costs gives the annual cost of expendables associated with repair actions (TEXPR):

$$TEXPR = TEXPRBS + TEXPRDS + TEXPRBU + TEXPRDU \qquad (26)$$

3C. Cost of Replacement of Condemned Parts

Eqs 27 and 28 calculate the cost of replacement of condemned parts. The term "replacement cost of a part" is synonymous with procurement cost. Eq 27 calculates the cost of replacement of parts condemned during of scheduled maintenance actions.

3c.1. Replacement Cost of Parts Condemned During Scheduled Maintenance Actions (CONDS)

$$\begin{aligned} CONDS = TSMA \times \{ & [QPESL \times (BCONDL + (NRTSL \times DCONDL) \times ACONDL] \\ & + [QPESM \times (BCONDM + (NRTSM \times DCONDM) \times ACONDM] \\ & + [QPESH \times (BCONDH + (NRTSH \times DCONDH) \times ACONDH] \} \end{aligned} \qquad (27)$$

Where the new terms are:

ACONDL = Average cost of procurement to replace a condemned category L part

ACONDM = Average cost of procurement to replace a condemned category M part

ACONDH = Average cost of procurement to replace a condemned category H part

Once a part is removed from the engine for repair, only one of three things can happen to it at the base level. It can: (1) be repaired at base level, (2) condemned at base level, or (3) sent to the depot level. At the depot it can either be repaired or condemned. The following example with hypothetical values is provided:

QPESL = Average number of category L parts removed for repair during a scheduled maintenance action = 100

RTSL = Average percent of QPESL that is repaired at base level = 60%

NRTSL = Average percent of QPESL that is sent to the depot level for repair = 30%

DCONDL = Average percent of NRTSL that is condemned at depot level = 20%

Out of the 100 parts removed for repair, if 60 percent are repaired at base and 30 percent are sent to depot, then 10 percent must be condemned at base level (1 - RTSL - NRTSL = 1 - 0.6 - 0.3). This 10 percent is the base condemnation rate for category L parts. The base condemnation rate of parts from category L is termed BCONDL. BCONDM and BCONDH represent the same concept for categories M and H. The following relationships apply:

BCONDL = 1 - RTSL - NRTSL

BCONDM = 1 - RTSM - NRTSM

BCONDH = 1 - RTSH - NRTSH

The total condemnation rate (base and depot) of category L parts can be represented by the term "BCONDL + (NRTSL x DCONDL)."

Using the numbers in this example, this rate would be:

$$
\begin{aligned}
\text{BCONDL} + (\text{NRTSL} \times \text{DCONDL}) &= 0.1 + (0.3 \times 0.2) \\
&= 0.1 + 0.06 \\
&= 0.16
\end{aligned}
$$

According to this example then, on the average, 16 percent of category L parts that were removed for repair during a scheduled maintenance action, are eventually condemned. Multiplying the total condemnation rate (BCONDL + (NRTSL x DCONDL) by the number of category L parts removed for repair during a scheduled maintenance action, yields the total number of category L parts that are condemned during one scheduled maintenance action. Multiplying this number by the total number of scheduled maintenance actions per year gives the total annual number of condemned parts from category L. And then multiplying this number by the average cost of replacing a condemned category L part, will produce the annual cost of replacing the condemned parts of the category L. Similar formulations would apply to the other two categories. This is the logic behind Eq 27 which calculated the annual procurement cost of replacing condemned parts that were removed due to scheduled maintenance actions.

3c.2. Replacement Cost of Parts Condemned During Unscheduled Maintenance Action

Eq 28, which is presented below, calculates the cost of procurement to replace items that were condemned during unscheduled maintenance actions.

$$
\begin{aligned}
\text{CONDU} = {} & [\text{TUMAL} \times \text{QPEUL} \times [\text{BCONDL} + (\text{NRTSL} \times \text{DCONDL})] \times \text{ACONDL}] \\
& + [\text{TUMAL} \times \text{QPESM} \times [\text{BCONDM} + (\text{NRTSM} \times \text{DCONDM})] \times \text{ACONDM}] \\
& + [\text{TUMAL} \times \text{QPESH} \times [\text{BCONDH} + (\text{NRTSH} \times \text{DCONDH})] \times \text{ACONDH}] \\
& + [\text{TUMAM} \times \text{QPESL} \times [\text{BCONDL} + (\text{NRTSL} \times \text{DCONDL})] \times \text{ACONDL}] \\
& + [\text{TUMAM} \times \text{QPEUM} \times [\text{BCONDM} + (\text{NRTSM} \times \text{DCONDM})] \times \text{ACONDM}] \\
& + [\text{TUMAM} \times \text{QPESH} \times [\text{BCONDH} + (\text{NRTSH} \times \text{DCONDH})] \times \text{ACONDH}] \\
& + [\text{TUMAH} \times \text{QPESL} \times [\text{BCONDL} + (\text{NRTSL} \times \text{DCONDL})] \times \text{ACONDL}] \\
& + [\text{TUMAH} \times \text{QPESM} \times [\text{BCONDM} + (\text{NRTSM} \times \text{DCONDM})] \times \text{ACONDM}] \\
& + [\text{TUMAH} \times \text{QPEUH} \times [\text{BCONDH} + (\text{NRTSH} \times \text{DCONDH})] \times \text{ACONDH}]
\end{aligned} \tag{28}
$$

Where the only new variable is:

CONDU = the total annual procurement cost of replacing condemned items that were removed from the engine for repair during unscheduled maintenance actions

Eq 28 is rather long because as the reader is familiar by now, unscheduled maintenance actions make it difficult to lump all three categories of the parts together because of the different treatment that the problem category receives in terms of the number of parts removed.

The sum of Eqs 27 and 28 provides the total annual cost of procurement to replace condemned items. This cost, termed TCONST, is the sum of CONDS (Eq 27) and CONDU (Eq 28):

$$\text{TCONST} = \text{CONDS} + \text{CONDU} \tag{29}$$

Total Cost According to Model-A

It was mentioned at the beginning of this chapter that the costs calculated by Model-A fell in the following three categories:

1. Costs To Perform Maintenance directly on the Engine

   1A. Labor costs associated with maintenance actions (TMALC, Eq 11)

   1B. Cost of fuel to do engine trims and checks (COSTFU, Eq 12)

2. Cost of Repairs

   2A. Annual repair cost at base level (BRTC, Eq 15)

   2B. Repair cost at depot level (DRTC, Eq 18)

3. Cost of Spares

   3A. Cost of expendables associated with maintenance of the engine (EXPM, Eq 21)

   3B. Cost of expendables associated with repair actions (TEXPR, Eq 26)

   3C. Cost of replacing condemned parts (TCONST, Eq 29)

The sum of these costs yields the total annual recurring costs associated with the repair and maintenance of a jet engine. Eq 30 then is the final equation of this model and it calculates the total cost (TOTCOST):

$$\begin{aligned} TOTCOST = {} & TMALC + COSTFU + BRTC + DRTC + EXPM \\ & + TEXPR + TCONST \end{aligned} \tag{30}$$

Summary of Chapter III

Chapter III has provided a detailed description of Model-A. The major categories of cost were specified. These categories were then divided into subcategories (for example: base level versus depot level), which were further broken down into lower levels of aggregation. This model uses 51 input variables and 30 equations. Most existing O&S cost models, as was mentioned in Chapter I, are similar to Model-A. They are detailed and require data for a large number of variables. Appendix B is a listing of the computer program that calculates costs according to Model-A.

IV. Methodology

Chapter III described Model-A which is an accounting type of cost estimating model. Model-A uses 51 input variables and 30 equations. Many existing O&S cost models are significantly larger. As stated earlier, the purpose of this research effort is to develop a CER that is capable of generating nearly the same cost estimates as Model-A.

The methodology employed to do this, involved collecting data which was to be obtained in the form of a range of values that each variable would fall within. This range would then be used as a basis for a simulation exercise that would generate 300 observations. Using the first 250 observations as the data base, multivariate linear regression analysis would be performed to develop a new cost estimating model; Model-S. The remaining 250 observations would be used to test the validity of Model-S.

Data Problem

This thesis effort ran into problems with the collection of data. The researcher was able to acquire the values, in the form of a range, of only a small minority of variables in Model-A. It was subsequently decided that since the emphasis of the research was on demonstration of a methodology, the research could continue by inputting the range values on a judgement basis. Each variable was

assigned three values: a lower bound, a most likely estimate and an upper bound.

Simulation

If one were to take, for instance, the most likely values of all 51 independent variables in this model, then that would account for one observation, which will yield a total cost figure if run through Model-A. In order to be able to perform linear regression, several observations are required. This was obtained through the use of simulation. In order to simulate, it was necessary to determine a distribution that would be most appropriate. This distribution was determined to be the triangular distribution. Often, when a minimum, maximum, and a most likely value can be ascertained, a triangular distribution can be used because these values are the only parameters needed to define a triangular distribution (2:134; 21:30).

A SAS (Statistical Analysis System) function called RANTRI, which is a random number function for a triangular distribution can be used to generate any number of observations. This function uses an argument to select an initial seed value, which initializes the random number stream (23:236-238). This method, generates all the numbers from the same stream. Even though the chances of thus inducing any correlation among the variables is slim, a more robust method is to use a different seed for each variable. This was done by using a "call subroutine" within the RANTRI

function. In generating these observations, it was assumed that all variables were independent of each other. In fact the idea of using a more robust method of random number generation was to preserve this independence. By running the simulated sets of data through Model-A, an equal number of total cost (TOTCOST) figures were generated. As a result, a data base was created which would be used to develop a new cost model, Model-S.

Development of Model-S

Identification: The first step in developing any cost model involves an identification of cost drivers. Cost drivers are those variables which affect cost in a significant way. A change in the value of a cost driver causes a noticeable change in cost. For example, the frequency of maintenance actions is a major determinant of maintenance costs. Frequency of maintenance is often driven by how often parts fail. Mean time between failure (MTBF), therefore would logically be a cost driver when trying to estimate maintenance costs.

Most of the variables in Model-A are very specific. It was felt that while they should be retained as potential candidates for cost drivers, some aggregrate variables needed to be created. One of the objectives of developing a cost estimating relationship (CER) is to facilitate easier estimation of the variables that are specified in the CER. Aggregate variables would be much easier to estimate than

variables that are as specific as most of the 51 original variables in Model-A. Secondly, if one wanted to affect or control costs by certain maintenance polcy decisions, it would be a lot easier; for example, to try to set an aggregate base repair rate than it would be to specify what percent of parts should be sent to depot of those category L parts that were removed for repair during an unscheduled maintenance action. This kind of variable is usually hard to estimate even for systems that are in operation much less for one that is in the beginning stages of acquisition. Descriptions of the new variables are provided here. The listing of the computer program in Appendix B provides the formulas for these variables. The following aggregrate variables were created:

MCOST = the average cost of doing those maintenance activities that are common to both scheduled and unscheduled maintenance actions

EXAS = the average cost of expendables associated with a scheduled maintenance action

EXAU = the average cost of expendables associated with an unscheduled maintenance action

EXM = the average cost of expendables associated with a maintenance action

TR = annual number of parts removed for repair

TRR = average number of parts removed per maintenance action

TRB = annual number of parts repaired at base

TRD = annual number of parts repaired at depot

BRT = Base repair rate, i.e., what percent of parts removed for repair annually is repaired at base?

DRT = depot repair rate, i.e., what percent of parts removed for repair annually is repaired at depot?

BURC = average unit repair cost at base

DURC = average unit repair cost at depot

URC = average unit repair cost

EXPPR = average cost of expendables per repair action

CMH = Cost per manhour

CONDR = Condemnation cost per repair action

MTBF = the aggregate mean time between failure, a figure that incorporates the MTBFs of the three different categories of cost

<u>Specification</u>: The second step in developing a cost model involves what is known as specification. Specification refers to the nature of the relationship that an independent variable has with the dependent variable. In other words, how does the dependent variable change with a change in the independent variable? For example, the number of scheduled maintenance actions (TSMA) is a function of operational hours (flying hours) and the scheduled maintenance interval (SMI):

$$TSMA = AFH/SMI \qquad (1)$$

where

AFH is the annual number of flying hours. Given that the number of operational hours stay the same, a decrease in

SMI would result in an increase in TSMA. Reducing SMI means that maintenance is performed more often which would result in higher maintenance costs assuming that by doing so, the reduction in failures is not large enough to offset the increase in cost. Everything else being constant, the smaller SMI gets, the larger the maintenance cost. Therefore, one would expect to see a negative or inverse relationship between SMI and cost.

Specification also deals with the issue of whether the relationship between a dependent variable and an independent variable is linear. It was assumed that all relationships are linear unless the statistics showed otherwise.

Regression Analysis(19)

Model-S was developed using multivariate regression analysis techniques. For a thorough understanding of multivariate regression analysis, one should refer to one of many texts that are avaialable on the subject. A brief discussion of univariate linear regression is included here.

> Regression analysis is a statistical tool that utilizes the relation between two or more quantitative variables so that one variable can be predicted from the other or others [31:23].

A basic regression model that is linear and has one independent variable can be expressed as:

$$Y_i = B_o + B_1 X_1 + E_i \qquad (31)$$

Where

Y_i = the value of the dependent variable in the ith trial

B_o and B_1 = parameters or coefficients

X_i = the value of the independent variable in the ith trial

E_i = a random error term with mean (expected value) = 0 and variance = σ^2

Since the expected value of the error term is zero, it follows that the expected value or the means of the response (dependent) variable for any given value of X is:

$$E(Y_i) = B_o + B_1X_i \tag{32}$$

The least squares method of regression analysis, also known as the best fit approach, considers the difference between the observed value of the dependent variable (Y_i) and its expected value ($B_o + B_1X_i$) and estimates B_o and B_1 by coming up with b_o and b_1 in a way that minimizes the square of the deviations between the observed value of Y_i and its expected value over n observations. This criterion is denoted by Q in the following expression:

$$Q = \sum_{i=1}^{n} (Y_i - B_o - B_1X_i)^2 \tag{33}$$

The estimators b_o and b_1 which minimize Q for any set of data are given by the following equations:

$$\sum Y_i = nb_o + b_1 \sum X_i \tag{34}$$

$$\sum X_i Y_i = b_o \sum X_i + b_1 \sum X_i^2 \tag{35}$$

The equations above are called normal equations and b_o and b_1 are called point estimators. b_o and b_1 can be obtained as follows:

$$b_1 = \sum (X_i - \bar{X})(Y_i - \bar{Y}) / \sum (X_i - \bar{X})^2 \tag{36}$$

$$b_o = \bar{Y} - b_1 \bar{X} \tag{37}$$

where $\bar{X}$ is the mean of the independent variable and $\bar{Y}$ is the mean of the observed value of the dependent variable. The least square estimators, b_o and b_1 are are unbiased and have minimum variance among all unbiased linear estimators. Given a set of observations then, the regression equation has the following format:

$$\hat{\hat{Y}} = b_o + b_1 X_i \tag{38}$$

where

$\hat{\hat{Y}}$ is the predicted value of the dependent variable.

<u>Stepwise Multiple Regression</u>: To develop Model-S, a SAS function called "Stepwise" was executed. Stepwise regression uses the least squares best fit criterion to estimate the coefficients of the independent variables in the model. This method adds variables one at a time to the model starting with the most statistically significant

variable first. Other variables are systematically added so long as they are significant at a specified level of confidence (85% confidence level in this case). If the inclusion of a new variable to the model results in the reduction of statistical significance of another variable that was already in the model to below 85 percent, then the affected variable is excluded from the model.

The stepwise procedure systematically includes all the ariables that are significant to the level desired and stops when none of the variables outside the model are significant to the level of confidence selected and all the variables inside the model are. Stepwise regression is a good way to get started towards the selection of a model even though it does not gurantee that the best possible model will be selected. The selection of a model often involves numerous iterations of modeling cost as a function of different combinations of variables and then evaluating the properties associated with the various models.

Model Evaluation Criteria

Signs of Regression Coefficents: The first things to check in the evalauation process of a model are the signs of the coefficients associated with the independent variables (cost drivers). Are these signs depicting a logical relationship between cost and the cost drivers?

<u>Standardized Regression Coefficients</u>: Regression coefficients are a measure of the change in the mean response per unit change in the independent variable when all other indepenent variables are held constant. However, the magnitude of these coefficients is influenced by the units used to express the independent variables. Therefore, comparing regression coefficients to evaluate the relative "weights" (influence on cost) of the independent variables is akin to comparing apples and oranges. To evaluate the relative weights of the variables in Model-S, standardized regression coefficients were used. Also known as beta coefficients, these statistics facilitate the comparison of regression coefficients. A beta coefficient is unitless; it measures the change in the mean response of the dependent variable (in units of standard deviations of the dependent variable) given a one standard deviation change in the independent variable while all other independent variables are held constant. Standardized regression coefficient of an independent variable is derived by the following formula:

$$\text{Beta1} = b_1 * (S_1/S_y) \qquad (39)$$

Where

Beta1 = the standardized regression coefficient for the independent variable 1

b_1 = the regression coefficient for independent variable 1

S_1 = the standard deviation of variable 1

S_y = the standard deviation of the observed values of the dependent variable Y

The interpretation of regression coefficients, however, standardized or not, gets blurred in the presence of collinearity, i.e., when the independent variables are correlated among themselves.

T-test: A t-test is employed to determine whether an individual independent variable in the model is making a significant contribution to the overall equation. The null hypothesis here is that the regression coefficient of a particular variable is equal to zero. The t-statistic is calculated by dividing the coefficient of the variable by the standard error of the coefficient. If this value exceeds the tabular t-statistic at 80+ percent confidence, then it is reasonable to conclude that the variable is making a significant contribution to the overall equation.

An analysis of variance (ANOVA) (Table I) is presented below to facilitate the understanding of certain model evaluation criteria.

The total sum squares (SST) is the sum of the squared differences between the observed value (Y_i) and the predicted value when the prediction is based on the regression line (Y). SST and SSE, therefore, are both measures of prediction error. The regression sum of squares (SSR_i) is the variation in Y explained by the regression line, and is also the difference between SST and SSE. It is a measure

Table I

Analysis of Variance

Source of Variation	Sum of Squares	Degree of Freedom	Mean Squares
Regression	SSR = $(\hat{Y}_i - Y)^2$	p-1	MSR = SSR/p-1
Error	SSE = $(Y_i - \hat{Y}_i)^2$	n-p	MSE = SSE/n-p
Total	SST = $(Y_i - Y)^2$	n-1	

where

$\hat{Y}_i$ = predicted value for the ith observation using the regression line

$\bar{Y}$ = mean of the observed values

Y_i = observed of the dependent variable

p = number of variables in the model including the integers

n = number of observations in the data set

of the amount of reduction in the predition error obtained when the prediction is based on the regression line is opposed to $\bar{Y}$.

F Ratio: Dividing SSR and SSE by their respective degrees of freedom yields the mean square regression (MSR) and the mean square error (MSE), respectively. The F-ratio is calculated as follows:

$$F_{calc} = MSR/MSE \qquad (40)$$

The F-ratio can be evaluated to determine the overall statistical significance of the estimating relationship of the model. The null hypothesis here is that every regression coefficient in the model that is associated with an independent variable is equal to zero. The calculated F value is compared to a tabular value of F at a certain confidence level at p-1/n-p degrees of freedom where p is the number of parameters and n is the sample size. If the F-ratio in the ANOVA table (F_{calc}) is greater than the tabular F-ratio at 90 percent level of confidence, then it would be reasonable to conclude that the overall relationship depicted by the model is statistically significant.

Coefficient of Determination: This statistic provides information about the strength of the relationship of the dependent variable with the independent variables. In order to calculate this, the total variation (SST) of the observed values from the expected or calculated values is partitioned into the sum-of-squares regression (SSR) and sum-of-squares error (SSE). R^2 is known as the coefficient of determination and basically tells one how much of the total deviation (SST) is explained by the regression line. R^2 can be expressed as follows:

$$R^2 = SSR/SST \tag{41}$$

The coefficient of determination, R^2 is also known as the goodness of fit measure and all things being equal, a higher R^2 is preferred.

Collinearity: The problem of collinearity occurs when an independent variable is nearly a linear combination of other independent variables in the model. The observations for the original 51 input variables in Model-A were independent because of the method used to generate the data. It was not expected that there would be any collinearity among them. A person's pairwise correlation index was obtained to confirm this. However, since new variables were created which were aggregation of the original variables, it was reasonable to expect that some collinearity might be introduced. Collinearity problems can cause unstable estimates and normally do inflate the variances of the variables involved. Therefore, collinearity diagnostics were used to determine the extent to which collinearity was affecting the model and to identify which variables were involved in collinear relationsh_ps.

The TOL and COLLINOINT options in the SAS regression procedure provide collinearity diagnostics. TOL stands for tolerance value. When subtracted from one, tolerence yields a muliple R^2 statistic. This statistic is a measure of how correlated a particular independent variable in the model is with other independent variables in the model. As

a criterion, tolerance values below 0.3 are signs of multicollinearity.

The collinoint option computes condition numbers. If all condition numbers equal one, there is no collinearity in the model. Increasing condition numbers indicate the degree of collinearity in the model. A condition number greater than 5 was considered to be high.

The condition number also computes the variance proportion of each regression coefficient. The sum of the variance proportions in each column equals 1. The presence of no more than one large variance proportion in any row indicates that there are no collinear relationships in the model. This will result in a low condition number. If on the other hand, there are more than one high variance proportion numbers in any row, there may be a problem with collinearity if this situation is accompanied by a high condition number in the same row. The following example (Table II) will help illustrate these concepts:

The condition number in row 6 is 5.43549. The variance proportion statistics (VAR PROP) in row 6 shows that variables 3 and 4 have high proportions associated with them. Similarly in row 7, variables 1 and 2 have high VAR PROP values and a condition number of 6.20098. These statistics indicate that variables X_1 and X_2 are correlated and so are variables X_3 and X_4. The condition number associated with these rows is high enough to warrant that

Table II

Collinearity Diagnostics

ROW	CONDITION NUMBER
1	1
2	1.06117
3	1.17564
4	1.51004
5	2.17646
6	5.43549
7	6.20098

ROW	VAR PROP X_1	VAR PROP X_2	VAR PROP X_3	VAR PROP X_4	VAR PROP X_5	VAR PROP X_6	VAR PROP X_7
1	0.0085	0.0057	0.0173	0.0170	0.0233	0.0153	0.0198
2	0.0194	0.0211	0.0109	0.0116	0.0034	0.0001	0.0026
3	0.0005	0.0038	0.0068	0.0070	0.1073	0.1477	0.0494
4	0.0000	0.0033	0.0001	0.0001	0.0025	0.1571	0.6295
5	0.0081	0.0014	0.0007	0.0023	0.5179	0.5528	0.1552
6	0.0098	0.0065	0.9479	0.9527	0.0000	0.0000	0.0049
7	0.9535	0.9583	0.0161	0.0094	0.3466	0.1271	0.1388

collinearity may be unduly influencing the model. Rows 1, 2, 3 and 4 do not have any high VAR PROP associated with them and the condition numbers in these rows are also low. Row 5 shows variables 5 and 6 involved in a moderate collinear relationship with variaance proportion numbers of 0.5179 and 0.5528. The condition number in row 5 is a moderate 2.17646 and it indicates that the collinearity between variables 5 and 6 is moderate at best.

Outliers: Outliers are extreme observations. An extreme observation may be an outlier either with respect to the regression line or with respect to the independent variables or both. Studentized residual (SRESID) is a statistic that identifies outliers with respect to the regression line. Its value is obtained by taking the residual (the difference between the observed value and the predicted value) and dividing it by appropriate standard error of the residuals. Studentized residuals follow a t-distribution and an observation with a studentized residual that falls outside the 90 percent confidence level of the t-statistic (n-p degrees of freedom) is an outlier with respect to the regression line.

Outliers with respect to independent variables are identified by a statistic called leverage value. Leverage value measures how far an observation is from a hypothetical observation which has the same characteris as the average values of the independent variables. A leverage value greater than 2p/n, where p is the number of parameters and n the sample size, indicates an outlier with respect to the independent variables.

An outlier is considered influential if by its presence, it is pulling the fitted regression line towards itself. This happens because the least quares best fit method tries to minimize the sum of squared deviations. SRESID and leverage value help identify outliers and are

also used to form a statistic called Cook's D. Whether an outlier is influential (pulling the regression line) or not is determined by checking Cook's D statistic (D_i). A Cook's D value higher than an F-ratio (p-1/n-p degrees of freedom) at 50 percent level of confidence indicates that the outlier is influential. The manner in which the data for this research was generated would normally create some outlying observations. Outlier statistics were used to identify observations that were influential outliers.

Measures of Predictive Ability of Model-S

The size of the standard error of the estimate is directly related to the overall ability of the model to predict. The square root of MSE (presented in the ANOVA table) is the standard error of the estimate.

The standard error divided by the mean of the dependent variable results in the coefficient of variation (C.V.) statistic. C.V. is the measure of the relative magnitude of the standard error. The predictive ability of Model-S was evaluated by analyzing the magnitude of the difference between the observed value and the predicted value. This difference is called the residual. Residuals were expressed as a percentage of the observed value. The predictive ability of Model-S was also evaluated by the width of its prediction intervals at 95 percent level of confidence. The prediction intervals indicate that the next observation will fall between the upper and lower bounds of the prediction

interval within a probaility equal to the level of confidence. The width of the prediction interval depends on the size of the standard error, the ability of the model to estimate the true population coefficents and the level of confidence. The lower the standard error and the better the ability of the model to estimate the population coefficients, the smaller the bound will be. These factors held constant, the higher the level of confidence, the wider the interval and vice-versa. The predictive ability of Model-S was evaluated by examining the magnitude of the bound and the bound expressed as a percentage of the predicted value.

Validation of Model-S

Models normally predict better the observations in the data set than they do observations not in the data set. This is so because the criterion used to develop a model is to maximize its predictive capability. One approach of validating a model is to withhold part of the data and not use it in the development of the model. These omitted observations can then be used to test the predictive ability of the model. During this research effort, 300 observations were generated out of which 250 were used to develop Model-S and the the last 50 observations were used to evaluate how the TOTCOST figures generated by Model-S compared to ones generated by Model-A.

Other Diagnostics

Because of the nature of the simulation used to generate the data, it was not necessary to test the assumptions that the error terms are normally distributed; that their distributions have the same variance (homoscedasticity) and that the error terms are independent of each other (no auto-correlation).

V. Analysis Of Results

Chapter Overview

This chapter contains the results of the data analysis. It presents Model-S, and analyzes its statistical properties.

Model-S

TOTCOST = -1,371,743 + 1,318,707 * NMA D 314,105 * TSMA
+ 572,799.3 * BRT + 907,253.4 * DRT
+ 14,550.22 * SQEXPPR - 83,640,101 * RECITTR
+ 20.95721 * MTBF

Where

NMA = Annual number of maintenance actions (scheduled & unscheduled)

TSMA = Annual number of scheduled maintenance actions

BRT = Base repair rate (a percent value)

DRT = Depot repair rate (a percent value)

SQEXPPR = Square root of the average cost of expendables per repair action

RECITRR = the reciprocal of TRR which stands for the average number of parts removed per maintenance action

MTBF = aggregate mean time between failure

The estimates of the coefficients and their levels of significance are presented in Table III. Also presented in this table are the standardized regression coefficients.

Table III

Parameter Estimates

Variable	Parameter Estimate	Standardized Estimate	T for H0: Parameter=0	PROB > |T|
INTERCEP	-1371743		-7.818	0.0001
NMA	1318707	0.5487198	16.107	0.0001
TSMAD	-314105	-0.0691199	-2.048	0.0417
BRT	572799.3	0.1019253	3.306	0.0011
DRT	907253.4	0.1281324	4.175	0.0001
SQEXPPR	14550.22	0.9303619	56.025	0.0001
RECITRR	-83640101	-0.44647	-31.744	0.0001
MTBF	20.95721	0.02730877	2.118	0.0352

Discussion

All variables in this model are significant to a high degree of confidence. Even the least significant variable, TSMA is significant at 95+ percent confidence (1 - 0.0417). Five of the independent variables are significant to the 99+ percent level of confidence.

The variable SQEXPPR (square root of cost of expendables per repair action) appears to be the most influential cost driver with the largest standardized

regression coefficient of 0.9303619. This indicates that a one standard change in SQEXPPR results in a 0.9303619 standard deviation change in TOTCOST. The variable EXPPR had always remained very significant in the Model-S development process; however when the residuals were plotted against this variable, it appeared that cost increased at a decreasing rate as EXPPR increased. The square root, natural log and reciprocal transformations were tried in an attempt to model this non-linear relationship. In this case, the square root transformation seemed to produce the best results.

Another variable that needed to be transformed was the variable TRR (average number of parts removed for repair per maintenance action). The plot of TRR against the residuals showed a similar pattern to the EXPPR plot; cost seemed to be increasing at a decreasing rate as TRR increased. In this case, however, a reciprocal transformation produced the best results.

The reciprocal of TRR (RECITRR) comes in the selected model with a high rate of significance (99.99%) and its standardized regression coefficient compares favorably with the other cost drivers in the model. TRR is positively correlated with cost; more parts removed during a maintenance means more repairs, more replacements and more condemnations. Therefore as TRR goes up, so does cost.

However, as TRR goes up, its reciprocal (1/TRR) goes down. RECITRR therefore has a negative regression coefficient.

EXPPR is followed by NMA (annual number of maintenance actions) with the second largest standardized regression coefficient (0.5487198). However, this variable is highly correlated with the variable TSMA (annual number of scheduled maintenance actions). Because of this collinearity, the standardized coefficient is hard to interpret. However, NMA comes in the model at the 99.9+ percent level of significance.

NMA equals the sum of TSMA and TUMA (annual number of unscheduled maintenance actions). Therefore these three variables (TSMA, TUMA and NMA) are correlated by definition. In the selected model, TSMA has a negative regression coefficient value of -314,105. Logic dictates that cost should increase as TSMA increases; the larger the number of maintenance activities, the larger the cost. In other words TSMA should be positively correlated with cost. One could suspect that the seemingly nonsensical regression coefficient of TSMA might be because of presence of collinearity. Often the presence of strong correlation can play havoc with the regression coefficents; however, in this case there is a logical reason for the negative coefficient of TSMA in this model. The way Model-A is structured, it requires the removal of a larger number of parts during an unscheduled maintenance action than it does during a

scheduled maintenance action. As such, an unscheduled maintenance action is typically costlier than a scheduled maintenance action. A model that has NMA as an independent variable but does not have TSMA or TUMA as one of its variables, can not distinguish whether a change in NMA is because of TSMA or TUMA. If NMA increases by one, it may be because TSMA increased by one or because TUMA increased by one. With respect to Model-S then, if one were to hold all the other variables constant with the exception of TSMA and NMA, the equation would look like this:

$$TOTCOST = 1,318,707 * NMA - 314,105 * TSMA$$

If TSMA goes up by one, so does NMA. The change in TSMA (ΔTSMA) is 1 and the change in NMA (ΔNMA) is also one. The change in the dependent variable (ΔTOTCOST) would be:

$$\Delta TOTCOST = (1,318,707 * \Delta NMA) - (314,105 * \Delta TSMA)$$

$$\Delta TOTCOST = (1,318,707 * 1) - (314,105 * 0)$$

$$\Delta TOTCOST = 1,318,707 - 314,105$$

$$\Delta TOTCOST = 1,004,602$$

It can be seen that if TSMA goes up by 1, TOTCOST increases by $1,004,602. If however, NMA were to go up by 1 because the number of unscheduled maintenance actions went up by one, then delta NMA (the change in NMA) would be 1 but delta TSMA would be zero because there is no increase in the

number of scheduled maintenace actions, only in the unscheduled ones. The change in TOTCOST would now be:

$$\Delta TOTCOST = (1,318,707 * \Delta NMA) - (314,105 * \Delta TSMA)$$

$$\Delta TOTCOST = (1,318,707 * 1) - (314,105 * 0)$$

$$\Delta TOTCOST = 1,318,707$$

One can see that when TUMA goes up by one, the increase in total cost is $1,318,707 while the increase in total cost with a similar increase in TSMA was $1,004,602. The difference between these two figures is $314,105 which happens to be the coefficient of TSMA. Thus, the regression coefficient of TSMA in the Model-S reflects the cost difference between a scheduled and a unscheduled maintenance action. In the presence of NMA in the model, the regression coefficient of TSMA has to be negative to adjust for this cost difference.

Base repair rate (BRT) and depot repair rate (DRT) are also selected as cost drivers. Base repair rate is the ratio of annual number of parts repaired at base divided by annual number of parts removed for repair. DRT similarly is the ratio of annual number of parts repaired at depot divided by the total number of parts removed for repair. This pair of variables can also be expressed as a function of each other. BRT, DRT and the total condemnation rate must sum to 1. This is so because any removed part will

either be repaired at base or at depot or will be condemned; there are no other possibilities. Generally, the more repairs that are performed at base level, the less the number of parts that will be sent to the depot for repair. There is an inverse relationship between BRT and DRT. As long as the condemnation rate stays fairly small, these two variables are highly correlated. As a result, it is difficult to change one while holding the other constant. Not being able to do this makes it difficult to interpret the regression coefficients.

The variable MTBF (aggregate mean time between failure) comes in the model at 96+ percent level of significance. Interestingly enough, it has a positive regression coefficient. On the surface again, this does not seem logical. As mean time between failure increases, failures go down. This should result in fewer unscheduled maintenance actions and therefore maintenance related costs should go down. Logically, then MTBF should come in the model with a negative coefficient. There are a few reasons why sometimes a variable that is negatively correlated with the dependent variable, shows up in the model with a positive regression coefficient and vice-versa. These reasons are:

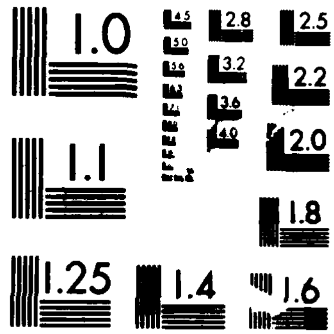
1. Anomaly in the data: If the data is clustered together, one bad observation away from the cluster is

AD-A186 923 THE USE OF COST ESTIMATING RELATIONSHIPS VERSUS 2/2

ACCOUNTING MODELS FOR EST (U) AIR FORCE INST OF TECH

WRIGHT-PATTERSON AFB OH SCHOOL OF SYST R S VERMA

UNCLASSIFIED SEP 87 AFIT/GSM/LSQ/87S-35 F/G 5/3 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

enough to change the direction of the regression line and produce unexpected signs in coefficients. This is not true of the data set used in this thesis because simulation under the triangular distribution would not produce clusters of data.

2. Statistical Fluke: When there are a few observations in the data set and the correlation between the dependent variable and the independent variable is a weak one (close to zero), the coefficient is liable to show up positive or negative due to the random variability in the sample. In this database, there are a large number of observations; so this reason can be discarded as well.

3. Characteristic of the Data: It is possible for a variable to have a statistical relationship to cost that is opposite to the logical relationship. This may happen when a variable in the model is capturing the effects of variables not in the model. In the following example, the variable V2 is negatively correlated with cost:

$$\text{Cost} = 60 + 11\ V1 - 6\ V2 \qquad (42)$$

Table IV provides some values for V1 and V2 and the resulting cost figures:

The data in Table IV shows that as V2 increases, so does cost. However Eq 42 showed that V2 was negatively related to cost. Because the data set in this research effort has numerous variables, and several three or four way

Table IV

Example Data Set

OBS	V1	V2	COST
1	7	2	125
2	10	3	152
3	16	4	212

correlationships may exist, it is possible that the positive coefficient of MTBF ocurrs because of such a phenomenon.

Model Statistics

The significance of the F-ratio, the magnitude of the coefficient of determination, and the small standard error of the estimate all indicate that from a statistical perspective, this is an outstanding model.

Table V shows that the model has an R^2 of 0.9686 which signifies that 96+ percent of the variation in the observed values of TOTCOST can be explained by this model. The F-ratio is by definition at least as significant as the least significant variable in the model, which in this case was over 95 percent. The F-ratio for the model is very large (1066.744) and is significant to the 99.999+ percent.

Table V

Analysis of Variance

DEP VARIABLE: TOTCOST

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	7	2.33347E+13	3.33352E+12	1066.744	0.0001
ERROR	242	756238323734	3124951751		
C TOTAL	249	2.40909E+13			

ROOT MSE	55901.27	R-SQUARE	0.9686
DEP MEAN	895426.5	C.V.	6.242976

The model has a small standard error of the estimate (6.24% of the mean of TOTCOST) and therefore prediction intervals of about 12 percent about the predicted value can be made with 95 percent confidence, when estimating at the middle of the data.

Collinearity

Tables VI and VII present the collinearity diagnostics:

The tolerance values for the variables NMA, TSMA, BRT, and DRT are underlined because they are low and indicate collinearity. The tolerance value for DRT is 0.1377179, which means that when regressed against the other variables in the model, DRT is correlated at 86+ percent (1-0.1377179). The other three variables have lower tolerence numbers and

Table VI

Collinearity Diagnostics

VARIABLE	TOLERANCE
NMA	0.1117691
TSMA	0.1138464
BRT	0.1364286
DRT	0.1377179
SQEXPPR	0.4703847
RECITRR	0.6557183
MTBF	0.7805896

are correlated to higher degrees. Next, Table VII shows the nature of these correlationships.

The condition number in row 6 is 5.43549. The variance proportion statistics (VAR PROP) in row 6 shows that variables BRT and DRT have high variance proportion values (.9479 and .9527) associated with them. Similarly in row 7, variables NMA and TSMA have high VAR PROP values (.9535 and .9583) and a condition number of 6.20098. These statistics indicate that variables NMA and TSMA are correlated and so are variables BRT and DRT. The conditions number associated with rows 6 and 7 are high enough to warrant that collinearity may be unduly influencing the model. Rows 1,2, 3 and 4 do not have any high VAR PROP associated with them and the condition numbers in these rows are small. Row 5 shows variables SQEXPPR and RECITTR involved in a moderate collinear relationship with variaance proportion numbers of

Table VII

Collinearity Diagnostics Variance Proportions

ROW	CONDITION NUMBER
1	1
2	1.06117
3	1.17564
4	1.51004
5	2.17646
6	5.43549
7	6.20098

ROW	VAR PROP X_1	VAR PROP X_2	VAR PROP X_3	VAR PROP X_4	VAR PROP X_5	VAR PROP X_6	VAR PROP X_7
1	0.0085	0.0057	0.0173	0.0170	0.0233	0.0153	0.0198
2	0.0194	0.0211	0.0109	0.0116	0.0034	0.0001	0.0026
3	0.0005	0.0038	0.0068	0.0070	0.1073	0.1477	0.0494
4	0.0000	0.0033	0.0001	0.0001	0.0025	0.1571	0.6295
5	0.0081	0.0014	0.0007	0.0023	0.5179	0.5528	0.1552
6	0.0098	0.0065	0.9479	0.9527	0.0000	0.0000	0.0049
7	0.9535	0.9583	0.0161	0.0094	0.3466	0.1271	0.1388

0.5179 and 0.5528. The condition number in row 5 is moderate at 2.17646 and it indicates that the collinearity between variables SQEXPPR and RECITTR is moderate at best. Last, the variance proportion number for SQEXPPR in row 7 is 0.3466 which indicates that it may be involved in a weak 3 way correlationship with NMA and TSMA. The collinearity between NMA and TSMA and between BRT and DRT was expected because both pairs of variables are correlated by definiton. Collinearity is not a problem if the relationship between

the involved variables is maintained outside the model also. This is true for both sets of variables. As has been explained earlier, both sets of variables are functionally related and therefore these relationships will always be maintained.

Outliers

Tables VIII and IX present outlier statistics:

Table VIII

Outliers With Respect To The Independent Variables (X)

OBS	LEVER	NMA	TSMA	BRT	DRT	SQEXPPR	RECITRR	MTBF
14	.065	-1.14	-1.07	-1.7	1.44	1.72	2.94	-0.39
49	.068	-0.33	0.00	.47	-0.51	1.85	3.05	-1.57
76	.069	-4.85	2.85	-2.01	2.23	-0.44	-0.35	-1.8
97	.090	2.30	0.92	-1.94	1.39	1.11	0.05	0.19
106	.070	1.00	1.25	-1.16	-0.04	1.16	1.70	1.12
159	.063	-1.92	-2.05	-0.38	-0.62	0.45	1.47	0.38
188	.064	-0.18	-0.45	0.96	-0.88	2.41	3.17	0.45
238	.061	2.68	3.05	-0.03	0.25	-0.96	0.35	0.18
245	.062	0.08	-0.66	-1.36	0.76	3.47	1.76	-0.87

In Table VIII, column 1 is the ith observation; column 2 has the leverage values and columns 3 thru 7 represent the seven variables of the model. Table VIII shows nine observations

where the leverage value either exceeded the criterion threshold of 0.064 or was close to it. These observations were analyzed in terms of the values of the seven variables in the model for those nine observations. Table VIII contains these values in terms of how many standard deviations they were away from their mean for those particular observations. Negative values indicate that the values were below their mean. All values that were two or more standard deviations away have been underlined in Table VIII. One can see that with the exception of observation 106, each observation had at least one variable that was an extreme value with respect to its mean, thus causing that observation to be an outlier with respect to the independent variables. Observation 106 has a leverage value of .070 (column 2) which does excced the criterion value of .064 (2p/n). This observation has six out of seven variables that are between one and two standard deviations away from their means so that even though no one particular variable is an extreme by itself, the combination of six moderately high values makes this observation an outlier.

<u>Outliers With Respect to the Regression Line</u>: There were 25 observations that had a higher studentized residual than than the t-statistic at the 90 percent level of confidence. At this level of confidence, one would expect approximately 10 percent of the observations to fall out of

bounds. Twenty-five happens to be exactly 10 percent of 250, the number of observations used to develop the model.

Influential Outliers: Cook's-D statistics indicated that there were no influential outliers. This is logical because, with 250 observations, it would be difficult for any one observation to exert any individual influence the regression line. The Cook's-D criterion was 0.907 and the largest Cook's-D value obtained was 0.110. Table IX lists seven observations that had the highest Cook's-D:

Table IX

Highest Cook's-D Values

CRITERION VALUE OBS	0.907 COOK'S-D	1.645 SRESID	0.064 LEVERAGE
133	0.110667	3.73700	.0596
10	0.108516	4.14060	.0481
238	0.105077	-3.57950	.0615
156	0.072863	3.57570	.0436
115	0.064065	2.82730	.0602
76	0.0519845	-2.35090	.0699
64	0.0517324	3.43060	.0339

Table IX presented the seven highest Cook's-D values and the associated SRESID and LEVERAGE value. None of the Cook's-D value comes close to the criterion value of 0.907;

however, in each of these cases SRESID is significantly above its criterion of 1.645. Observation 76 is an outlier both with respect to the regression line and the independent variables with a leverage value of 0.069. It is the only observation in this group which exceeded its leverage value criterion of 0.064. Appendix D of this thesis contains a complete listing of outlier statistics.

Predictive Ability of Model-S

The predictive ability of Model-S was evaluated by analyzing both the magnitude of the difference between the observed value and the predicted value (point estimates) and the width of the 95 percent prediction interval for each observation.

Point Estimates:

Ninety percent of the predicted cost values by Model-S were within 10 percent or less of the TOTCOST value generated by Model-A. The estimating error ranged from a low of $1,969 (less than two/tenth of a percent of actual cost) to a high of $134,993 (35 percent of actual cost). Table X presents some selected observations.

In Table X, column 1 is the ith observation, column 2 is the TOTCOST figure generated by Model-A, column 3 is the predicted figure by Model-S (YHAT), column 4 is the difference between the two (TOTCOST-YHAT), and column 5 is this difference expressed as a percent of TOTCOST ((RESID/TOTCOST) x 100).

Table X

Observations of Predictive Cost

OBS	TOTCOST	YHAT	RESID	RESIDPC
5	1,263,076	1,268,530	-5454	-0.432
12	581,691	584,646	-2955	-0.508
31	803,755	798,061	5694	0.708
67	1,112,055	1,114,024	-1969	-0.177
137	973,661	976,777	-3116	-0.320
143	724,020	727,089	-3070	-0.424
74	462,264	345,073	117,190	25.35
78	463,403	327,006	136,396	29.43
58	427,889	307,868	120.020	28.049
115	456,871	303,656	153,215	33.536
208	382,217	248,224	134,993	35.226

To be able to estimate 90 percent of the observations to within 10 percent of the actual, speaks well for Model-S' predictive ability.

A pattern was noted with the observations where Model-S had large estimating errors. Wherever the estimation error (RESID) is large, the associated TOTCOST value is relatively small. Furthermore, in each of these instances Model-S has not only missed the mark, it has consistently under-estimated. The mean value of TOTCOST is $895,426. Out of

the 250 observations, there are eight observations where the estimating error is 20 percent or greater. In seven of these TOTCOST has been in the 400,000 - 500,000 range and each of these seven times, the estimation has been lower yet.

The fact that almost everytime Model-S has under-estimated when estimating errors have been 20 percent or above and also that in most these instances TOTCOST has been below $500,000, led the researcher to speculate that the distribution of TOTCOST might not be normal. In fact, if the distribution of TOTCOST were to be right skewed, these results would make sense because the low values of TOTCOST would not occur in the far left tail as they would in a normal distribution. Model-S which assumes that error terms are normally distributed would place an equivalent number of values in each tail of a symmetrical distribution except that in the left tail of the distribution, it would miss the low values of TOTCOST because they are skewed to the right. Indeed, under such a scenario the regresssion based model would consistently under-estimate the low values of TOTCOST.

A measure of skewness test was run which generated a skewness statistic of 0.977. A normal distribution generates a skewness statistic of close to zero. Left skewed distributions generate negative values and right skewed distributions generate positive values. The test to see how skewed a distribution is requires comparing the

skewness statistic to its standard deviation calculated by the expression "$\sqrt{(6/n)}$." With n equal to 250, this number is equal to 0.155. The skewness statistic of 0.977 is, therefore, six standard deviations away from zero which means that the distribution of TOTCOST is extremely skewed to the right.

Appendix E is a complete listing of Table X.

Prediction Intervals

Table XI presents data which is in the form of prediction intervals constructed at 95 percent confidence level around the predicted value:

Table XI

Observations of Predictive Intervals

OBS	YHAT	L95	U95	BOUND	BOUNDPC
5	1,268,530	1,156,853	1,380,207	111,677	8.80
12	584,646	473,486	695,805	111,159	19.01
10	1,792,748	1,680,009	1,905,487	112,739	6.28
67	1,114,024	1,002,447	1,225,601	111,577	10.01
115	303,656	190,270	417,041	113,385	37.34
58	307,868	196,040	419.696	111,828	36.32
78	327,006	215,459	438,553	111,547	34.11

In Table X, column 1 is the ith observation; column 2 is the predicted cost by Model-S (YHAT); columns 3 and 4 are the lower and upper bounds respectively (L95 and U95). Column 5 represents the bound; it is the differnce between U95 and YHAT which is the same difference between YHAT and L95. Finally, column 6 in table 9 is a term called BOUNDPC which is the bound expressed as a percent of YHAT ((Bound/YHAT) x 100). BOUNDPC (column 6) ranged from a low of approximately six percent to a high of 41 percent. It was observed that even though BOUNDPC fluctuates, the bound itself remains between 111,000 to 113,000. The size of the bound is a function of the standard error of the model and its ability to have regression coefficients that are close to the poulation coefficients. A large data base typically allows the model to better estmate the population. It is because of this strength of the model that is keeping the bound very stable. A complete listing of the prediction intervals is provided in Appendix F.

Validation of Model-S

Of the three hundred observations that were generated, 50 were withheld from being used to develop Model-S. Because models generally predict observations in the data set better than they do observations not in the data set, this data was used to evaluate the validity of Model-S, i.e., its predictive accuracy. YHATs, point estimates of

Model-S were compared with TOTCOST. Table XII presents the results:

Table XII

Predictive Accuracy

OBS	TOTCOST	YHAT	DIFF	PERDIFF
251	6957966	58914	36882	5.30
252	1060244	1085562	-25318	-2.38
253	1044413	1044454	-41	-0.004
257	838258	948801	110543	-13.18
266	339264	153774	185489	54.67
269	601497	584518	16979	2.82
283	456575	334403	122172	26.75
284	629188	615957	13232	2.10
285	1130761	1135019	-4258	-0.37

In Table XII, column 1 is the ith observation; column 2 is the TOTCOST figure generated by Model-A; column 3 is the YHAT estimate of Model-S; column 4 is the difference of the two and column five is this difference expressed as a percent of TOTCOST ((DIFF/TOTCOST) x 100).

Out of the 50 observations, 43 observations were within 10 percent or less of TOTCOST; furthemore 31 of these observations were within 5 percent or less. Of the seven

observations that were over 10 percent away, three were between 10 percent and 20 percent; another three were between 20 percent and 30 percent and observation number 266 was unique because it differed by 54 percent. This observation happens to be the lowest TOTCOST value and in keeping with the lcgic of its skewed distribution, this error is understandable. With this one exception, Model-S seems to have performed quite accurately. Appendix F provides a complete listing of Table XII.

VI. Conclusions

Because the data for this research effort was artificially generated, the results of Model-S are not valid for cost-estimating purposes. However, the purpose of demonstrating methodology was served. The research questions posed in Chapter I have been answered by this thesis.

Model-A has 51 variables. In terms of identifying cost drivers, it was felt that an aggregation of some of those 51 variables was necessary. Variables such as "annual number of maintenance actions (NMA)" and "base repair rate (BRT)" are two of twenty such variables that are aggregations of the original 51 and were tested for their influence on cost. It would have been entirely possible to consider only the original 51 variables for selection in the model and perhaps still come up with a Cost Estimating Relationship (CER) that would have been equally good statistically. However, it would have been extremely difficult, given that one is trying to cost a new weapon system, to estimate these variables because they are extremely specific.

The selection of variables like NMA, TSMA (annual repair rate) in Model-S also affords one the opportunity to control these costs to some extent. Base repair rate (BRT) and depot repair rate are, to an extent, policy driven. The

number of scheduled maintenance actions is entirely dependent on flying hours and the scheduled maintenance interval. Both these variables can be influenced by policy decisions.

In Model-S the variables TSMA and MTBF (aggregate mean time between failure) came in with signs that were opposite of what would be logically expected. Often during multivariate regression analysis, combinations of variables can prevent pictures that on the surface seem illogical. The negative coefficient of TSMA in Model-S is a good case in point. These scenarios need to be analyzed further and not discarded immediately because there is a chance that the behavior indeed does make sense. As it turned out, in every instance the variable TSMA added strength and explanatory power to the model. It was not too long before it was discovered why the negative coefficient of TSMA made all the sense in the world, given that NMA was present in the model. The negative sign of TSMA in Model-S which also had NMA as a variable was to reflect the cost difference between a scheduled maintenance and an unscheduled maintenance action. It was not as easy to determine why MTBF came in the model with a positive sign. The characteristic of the data sometime causes such phenomenon. Since in each case, MTBF added a good deal of significance to the overall CER and came in individually significant also, the decision was made to keep it in the model.

The functional relationship of cost with the dependent variable needs to be determined statistically. Though it may be apparent that cost should go up or down with the increase or decrease in a particular variable, does it go up or go down with a decreasing rate? In Model-S the variables EXPPR and TRR needed to be transformed because their relationship with cost was not linear.

The variables EXPPR (average coat of expendables) and TRR (average number of parts removed per maintenance action) appeared to be related to cost in a nonlinear manner. Cost increased at a decreasing speed as either one of these variables increased. These variables were transformed into the square root (SQEXPPR) and the reciprocal (RECITRR). Both transformed variables were selected for inclusion in Model-S. EPRPR is the most individually significant variable in the model. The variable SQEXPPR (square root of the average cost of expendables per repair action) was the most significant cost driver in the model with the highest standardized regression coefficient.

Statistically, Model-S is an outstanding model. It has very high explanatory power; it can explain 96 percent of the variation in observed cost. All variables are significant at least to the 95 percent level. The overall model is significant to the 99.999 percent level of confidence.

The inclusion of NMA, TSMA, BRT, and DRT caused the presence of collinearity in the model. However, since NMA and TSMA are functionally related just as BRT and DRT are, collinearity was not considered to be a problem.

Out of 250 observations, there were none observations that were outliers with respect to the independent variables. In eight of these cases, at least one variable had an extreme value that fell more than two standard deviations away from its mean. There were 25 observations that were outliers with respect to the regression line meant that 10 percent of the observations fell out of the bounds t-statistic at 90 percent level of confidence. This was perfectly normal.

Model-S was estimated within ten percent or less for actual values for 90 percent of the observations. It predictive ability was also tested with observations that were withheld from being used in its development. This is one way to validate a model. The results were equally good. Where estimating errors were large, Model-S consistently underestimated observations that turned out to be relatively low values as well. This was because, as it was discovered, the cost figures generated by Model-A (TOTCOST) were not normally distributed. Instead this distribution was right skewed.

Suggestion for Future Research

In this research effort, data was generated through simulation with the assumption that the independent variables were not correlated among themselves. As a result, during simulation, the variables were essentially free to take on any value within their respective bounds. Real world data, of course, would not be independent. Therefore, the methodology of generating observations in this manner would create some unrealistic combination of variables. For example, if variables A and B both can range from 1 to 10 but they are correlated so that if A has a value of 9 then B could only be a number above 5, then a value of 9 for A and 3 for B is an unrealistic combination. The simulation procedure used in this effort could create such combinations because of the assumption of independence. With more realistic data, the simulation process would have to take the dependencies in consideration and impose limits other than the just the rang of a given variable. When a large number of variables are involved, multiple correlations can make such simulation a real challenge. A study would be done that repeats the methodology of this research with this particular modification.

Appendix A: Glossary of Input Variables for Model-A

1. ACONDH = Average cost of procurement to replace a condemned item from category H.

2. ACONDL = Average cost of procurement to replace a condemned item from category L.

3. ACONDM = Average cost of procurement to replace a condemneditem from category M.

4. AFH = Annual flying hours per engine.

5. BURCH = The average base level cost of repair of a part from category H.

6. BURCL = The average base level cost of repair of a part from category L.

7. BURCM = The average base level cost of repair of a part from category M.

8. CMH = average cost per manhour for personnel directly involved in maintenance/repair activity of jet engines.

9. DCONDH = Of those parts of category H that are sent to the depot for repair, DCONDL is a percent that on the average, is condemned at the depot level.

10. DCONDL = Of those parts of category L that are sent to the depot for repair, DCONDL is a percent that on the average, is condemned at the depot level.

11. DCONDM = Of those parts of category M that are sent to the depot for repair, DCONDL is a percent that on the average, is condemned at the depot level.

12. DURCH = The average depot level cost of repair of a part from category H.

13. DURCL = The average depot level cost of repair of a part from category L.

14. DURCM = The average depot level cost of repair of a part from category M.

15. EXPRBH = the average cost of expendables associated with a base level repair action on category H parts.

16. EXPRBL = the average cost of expendables associated with a base level repair action on category L parts.

17. EXPRBM = the average cost of expendables associated with a base level repair action on category M parts.

18. EXPRDH = the average cost of expendables associated with a depot level repair action on category H parts.

19. EXPRDL = the average cost of expendables associated with a depot level repair action on category L parts.

20. EXPRDM = the average cost of expendables associated with a depot level repair action on category M parts.

21. EXPSH = the average cost of expendables associated with category H parts with each scheduled maintenance action.

22. EXPSL = the average cost of expendables associated with category L parts with each scheduled maintenance action.

23. EXPSM = the average cost of expendables associated with category M parts with each scheduled maintenance action.

24. EXPUH = the average cost of expendables associated with category H with each unscheduled maintenance action caused by a problem with category H part(s).

25. EXPUL = the average cost of expendables associated with category L with each unscheduled maintenance action caused by a problem with category L part(s).

26. EXPUM = the average cost of expendables associated with category M with each unscheduled maintenance action caused by a problem with category M part(s).

27. FUEL = Cost of fuel per gallon.

28. FUELTC = average number of gallons of fuel required to test the engine after repair.

29. FUELTP = average number of gallons of fuel required to trim the engine while removed.

30. MHIE = Average number of manhours needed to install an engine; this includes the time required to transport the engine back.

31. MHRE = Average number of manhours needed to remove an engine; this includes the time required to transport the engine to the repair facility.

32. MHSMA = Average number of manhours needed to perform "on hands" maintenance for a scheduled maintenance action. This refers to the time consumed doing actual maintenance related chores such as removing and replacing parts, etc.

33. MHTB = Average number of manhours needed to do test bed run.

34. MHTE = Average number of manhours needed to trim an engine.

35. MHUMA = Average number of manhours needed to perform "on hands" maintenance for an unscheduled maintenance action. This refers to the time consumed doing actual maintenance related chores such as removing and replacing parts, etc.

36. MTBFH = Given that there is no preventative maintenance, the amount of time the engine will operate before it needs to be removed for repair because of a problem with category H part(s).

37. MTBFL = Given that there is no preventative maintenance, the amount of time the engine will operate before it needs to be removed for repair because of a problem with category L part(s).

38. MTBFM = Given that there is no preventative maintenance, the amount of time the engine will operate before it needs to be removed for repair because of a problem with category M part(s).

39. NRTSH = is the average percent of the parts removed from category H for repair, that is sent to the depot level.

40. NRTSL = is the average percent of the parts removed from category L for repair, that is sent to the depot level.

41. NRTSM = is the average percent of the parts removed from category M for repair, that is sent to the depot level.

42. QPESH = average number of parts,coded for repair, removed from the category H during a scheduled maintenance action.

43. QPESL = average number of parts, coded for repair, removed from category L during a scheduled maintenance action.

44. QPESM = average number of parts, coded for repair, removed from category M during ascheduled maintenance action.

45. QPEUH = Given that the engine was removed for repair because of a problem with category H part(s) (causing unsheduled maintenance), QPEUH is the average number of parts, coded for repair, that are removed from category H?

46. QPEUL = Given that the engine was removed for repair because of a problem with category L part(s) (causing unsheduled maintenance), QPEUL is the average number of parts, coded for repair, that are removed from category L.

47. QPEUM = Given that the engine was removed for repair because of a problem with category M part(s) (causing unsheduled maintenance), QPEUM is the average number of parts, coded for repair, that are removed from category M?

48. RTSH = is the average percent of the parts, removed from the category H for repair, that is repaired at base level (as opposed to being sent to depot or being condemned).

49. RTSL = is the average percent of the parts, removed from the category L for repair, that is repaired at base level (as opposed to being sent to depot or being condemned).

50. RTSM = is the average percent of the parts, removed from the category M for repair, that is repaired at base level (as opposed to being sent to depot or being condemned).

51. SMI = Scheduled maintenance interval.

Appendix B: SAS Computer Program for Running Model-A

```
OPTIONS LINESIZE = 80;
LIBNAME RAJ '[RVERMA]';
DATA _null_;
SEED1=66065; SEED2=31060; SEED3=85269; SEED4=63573; SEED5=73796;
SEED6=98520; SEED7=11805; SEED8=83452; SEED9=88685; SEED10=99594;
SEED11=65481; SEED12=80124; SEED13=74350; SEED14=69916; SEED15=09893;
SEED16=91499; SEED17=80336; SEED18=44104; SEED19=12550; SEED20=63606;
SEED21=61196; SEED22=15474; SEED23=94557; SEED24=42481; SEED25=23523;
SEED26=04493; SEED27=00549; SEED28=35963; SEED29=59808; SEED30=46058;
SEED31=32179; SEED32=69234; SEED33=19565; SEED34=45155; SEED35=94864;
SEED36=98086; SEED37=33185; SEED38=80951; SEED39=79752; SEED40=18633;
SEED41=74029; SEED42=54178; SEED43=11664; SEED44=48324; SEED45=69074;
SEED46=32533; SEED47=04805; SEED48=68953; SEED49=02529; SEED50=99970;
SEED51=74717;
L1 = 200;   M1 = 250;   H1 = 350;
L2 = 500;   M2 = 750;   H2 = 1000;
L3 = 1000;  M3 = 2000;  H3 = 5000;
L4 = 5000;  M4 = 7000;  H4 = 10000;
L5 = 500;   M5 = 750;   H5 = 1000;
L6 = 25;    M6 = 50;    H6 = 100;
L7 = 5;     M7 = 25;    H7 = 50;
L8 = 1;     M8 = 5;     H8 = 10;
L9 = 35;    M9 = 65;    H9 = 125;
L10= 10;    M10= 30;    H10= 75;
L11= 1;     M11= 10;    H11= 25;
L12= .5;    M12= .65;   H12= .8;
L13= .25;   M13= .5;    H13= .75;
L14= 0;     M14= .25;   H14= .4;
L15= .8;    M15= .65;   H15= .5;
L16= .75;   M16= .85;   H16= .9;
L17= .75;   M17= .85;   H17= 1;
L18= .1;    M18= .2;    H18= .3;
L19= .05;   M19= .15;   H19= .25;
L20= .05;   M20= .10;   H20= .15;
L21= 60;    M21= 100;   H21= 175;
L22= 150;   M22= 300;   H22= 500;
L23= 700;   M23= 1000;  H23= 1500;
L24= 150;   M24= 350;   H24= 700;
L25= 750;   M25= 1250;  H25= 1700;
L26= 1500;  M26= 2000;  H26= 3000;
L27= 10;    M27= 12;    H27= 15;
L28= 10;    M28= 12;    H28= 15;
L29= 5;     M29= 6;     H29= 7.5;
L30= 4;     M30= 6;     H30= 10;
L31= 500;   M31= 750;   H31= 1000;
L32= 800;   M32= 1200;  H32= 1500;
L33= 1000;  M33= 1500;  H33= 2500;
L34= 2500;  M34= 5000;  H34= 10000;
```

```
L35= 7500;  M35= 10000; H35= 15000;
L36= 1500;  M36= 2500;  H36= 4000;
L37= 3000;  M37= 6000;  H37= 12000;
L38= 8000;  M38= 12000; H38= 17500;
L39= 50;    M39= 75;    H39= 125;
L40= 125;   M40= 250;   H40= 500;
L41= 375;   M41= 500;   H41= 750;
L42= 100;   M42= 150;   H42= 250;
L43= 250;   M43= 500;   H43= 1000;
L44= 750;   M44= 1000;  H44= 1500;
L45= 250;   M45= 500;   H45= 1000;
L46= 1500;  M46= 10000; H46= 20000;
L47= 25000; M47= 35000; H47= 50000;
L48= 175;   M48= 200;   H48= 300;
L49= 125;   M49= 150;   H49= 200;
L50= .60;   M50= .75;   H50= 1.00;
L51= 12;    M51= 16;    H51= 25;
DO I     = 1 TO 300;
            CALL RANTRI (SEED1,(M1-L1)/(H1-L1),X1);
AFH      =   (H1-L1)*X1+L1;
REP +1;
            CALL RANTRI (SEED2,(M2-L2)/(H2-L2),X2);
MTBFL    =   (H2-L2)*X2+L2;
            CALL RANTRI (SEED3,(M3-L3)/(H3-L3),X3);
MTBFM    =   (H3-L3)*X3+L3;
            CALL RANTRI (SEED4,(M4-L4)/(H4-L4),X4);
MTBFH    =   (H4-L4)*X4+L4;
            CALL RANTRI (SEED5,(M5-L5)/(H5-L5),X5);
SMI      =   (H5-L5)*X5+L5;
            CALL RANTRI (SEED6,(M6-L6)/(H6-L6),X6);
QPESL    =   (H6-L6)*X6+L6;
            CALL RANTRI (SEED7,(M7-L7)/(H7-L7),X7);
QPESM    =   (H7-L7)*X7+L7;
            CALL RANTRI (SEED8,(M8-L8)/(H8-L8),X8);
QPESH    =   (H8-L8)*X8+L8;
            CALL RANTRI (SEED9,(M9-L9)/(H9-L9),X9);
QPEUL    =   (H9-L9)*X9+L9;
            CALL RANTRI (SEED10,(M10-L10)/(H10-L10),X10);
QPEUM    =   (H10-L10)*X10+L10;
            CALL RANTRI (SEED11,(M11-L11)/(H11-L11),X11);
QPEUH    =   (H11-L11)*X11+L11;
            CALL RANTRI (SEED12,(M12-L12)/(H12-L12),X12);
RTSL     =   (H12-L12)*X12+L12;
            CALL RANTRI (SEED13,(M13-L13)/(H13-L13),X13);
RTSM     =   (H13-L13)*X13+L13;
            CALL RANTRI (SEED14,(M14-L14)/(H14-L14),X14);
RTSH     =   (H14-L14)*X14+L14;
            CALL RANTRI (SEED15,(M15-L15)/(H15-L15),X15);
KL       =   (H15-L15)*X15+L15;
            CALL RANTRI (SEED16,(M16-L16)/(H16-L16),X16);
KM       =   (H16-L16)*X16+L16;
            CALL RANTRI (SEED17,(M17-L17)/(H17-L17),X17);
KH       =   (H17-L17)*X17+L17;
```

```
                CALL RANTRI (SEED18,(M18-L18)/(H18-L18),X18);
DCONDL   =      (H18-L18)*X18+L18;
                CALL RANTRI (SEED19,(M19-L19)/(H19-L19),X19);
DCONDM   =      (H19-L19)*X19+L19;
                CALL RANTRI (SEED20,(M20-L20)/(H20-L20),X20);
DCONDH   =      (H20-L20)*X20+L20;
                CALL RANTRI (SEED21,(M21-L21)/(H21-L21),X21);
BURCL    =      (H21-L21)*X21+L21;
                CALL RANTRI (SEED22,(M22-L22)/(H22-L22),X22);
BURCM    =      (H22-L22)*X22+L22;
                CALL RANTRI (SEED23,(M23-L23)/(H23-L23),X23);
BURCH    =      (H23-L23)*X23+L23;
                CALL RANTRI (SEED24,(M24-L24)/(H24-L24),X24);
DURCL    =      (H24-L24)*X24+L24;
                CALL RANTRI (SEED25,(M25-L25)/(H25-L25),X25);
DURCM    =      (H25-L25)*X25+L25;
                CALL RANTRI (SEED26,(M26-L26)/(H26-L26),X26);
DURCH    =      (H26-L26)*X26+L26;
                CALL RANTRI (SEED27,(M27-L27)/(H27-L27),X27);
MHRE     =      (H27-L27)*X27+L27;
                CALL RANTRI (SEED28,(M28-L28)/(H28-L28),X28);
MHIE     =      (H28-L28)*X28+L28;
                CALL RANTRI (SEED29,(M29-L29)/(H29-L29),X29);
MHTE     =      (H29-L29)*X29+L29;
                CALL RANTRI (SEED30,(M30-L30)/(H30-L30),X30);
MHTB     =      (H30-L30)*X30+L30;
                CALL RANTRI (SEED31,(M31-L31)/(H31-L31),X31);
MHSMA    =      (H31-L31)*X31+L31;
                CALL RANTRI (SEED32,(M32-L32)/(H32-L32),X32);
MHUMA    =      (H32-L32)*X32+L32;
                CALL RANTRI (SEED33,(M33-L33)/(H33-L33),X33);
EXPSL    =      (H33-L33)*X33+L33;
                CALL RANTRI (SEED34,(M34-L34)/(H34-L34),X34);
EXPSM    =      (H34-L34)*X34+L34;
                CALL RANTRI (SEED35,(M35-L35)/(H35-L35),X35);
EXPSH    =      (H35-L35)*X35+L35;
                CALL RANTRI (SEED36,(M36-L36)/(H36-L36),X36);
EXPUL    =      (H36-L36)*X36+L36;
                CALL RANTRI (SEED37,(M37-L37)/(H37-L37),X37);
EXPUM    =      (H37-L37)*X37+L37;
                CALL RANTRI (SEED38,(M38-L38)/(H38-L38),X38);
EXPUH    =      (H38-L38)*X38+L38;
                CALL RANTRI (SEED39,(M39-L39)/(H39-L39),X39);
EXPRBL   =      (H39-L39)*X39+L39;
                CALL RANTRI (SEED40,(M40-L40)/(H40-L40),X40);
EXPRBM   =      (H40-L40)*X40+L40;
                CALL RANTRI (SEED'1,(M41-L41)/(H41-L41),X41);
EXPRBH   =      (H41-L41)*X41+L41;
                CALL RANTRI (SEED42,(M42-L42)/(H42-L42),X42);
EXPRDL   =      (H42-L42)*X42+L42;
                CALL RANTRI (SEED43,(M43-L43)/(H43-L43),X43);
EXPRDM   =      (H43-L43)*X43+L43;
                CALL RANTRI (SEED44,(M44-L44)/(H44-L44),X44);
```

```
EXPRDH   =   (H44-L44)*X44+L44;
             CALL RANTRI (SEED45,(M45-L45)/(H45-L45),X45);
ACONDL   =   (H45-L45)*X45+L45;
             CALL RANTRI (SEED46,(M46-L46)/(H46-L46),X46);
ACONDM   =   (H46-L46)*X46+L46;
             CALL RANTRI (SEED47,(M47-L47)/(H47-L47),X47);
ACONDH   =   (H47-L47)*X47+L47;
             CALL RANTRI (SEED48,(M48-L48)/(H48-L48),X48);
FUELTP   =   (H48-L48)*X48+L48;
             CALL RANTRI (SEED49,(M49-L49)/(H49-L49),X49);
FUELTC   =   (H49-L49)*X49+L49;
             CALL RANTRI (SEED50,(M50-L50)/(H50-L50),X50);
FUEL     =   (H50-L50)*X50+L50;
             CALL RANTRI (SEED51,(M51-L51)/(H51-L51),X51);
CMH      =   (H51-L51)*X51+L51;
PL       =   1 - EXP (-SMI/MTBFL);
PM       =   1 - EXP (-SMI/MTBFM);
PH       =   1 - EXP (-SMI/MTBFH);
NRTSL    =   KL * (1-RTSL);
NRTSM    =   KM * (1-RTSM);
NRTSH    =   KH * (1-RTSH);
MTBF     =   (MTBFL+MTBFM+MTBFH)/3;
TSMA     =   AFH/SMI;
TUMAL    =   PL * TSMA;

TUMAM    =   PM * TSMA;

TUMAH    =   PH * TSMA;

TUMA     =   TUMAL + TUMAM + TUMAH;

NMA      =   TUMA + TSMA;

BRTCS    =   TSMA *((QPESL*RTSL*BURCL)+ (QPESM*RTSM*BURCM)
             + (QPESH*RTSH*BURCH));

BRTCU    =   TUMAL *((QPEUL*RTSL*BURCL) + (QPESM*RTSM*BURCM)
             + (QPESH*RTSH*BURCH)) + TUMAM*((QPESL*RTSL*BURCL)
             + (QPEUM*RTSM*BURCM) + (QPESH*RTSH*BURCH))
             + TUMAH*((QPESL*RTSL*BURCL) + (QPESM*RTSM*BURCM)
             + (QPEUH*RTSH*BURCH));

BRTC     =   BRTCS + BRTCU;

DRTCS    =   TSMA *((QPESL*NRTSL*(1-DCONDL)*DURCL)
             + (QPESM*NRTSM*(1-DCONDM)*DURCM)
             + (QPESH*NRTSH*(1-DCONDH)*DURCH));

DRTCU    =   TUMAL *((QPEUL*NRTSL*(1-DCONDL)*DURCL)
             + (QPESM*NRTSM*(1-DCONDM)*DURCM)
             + (QPESH*NRTSH*(1-DCONDH)*DURCH))
             + TUMAM * ((QPESL*NRTSL*(1-DCONDL)*DURCL)
```

```
              + (QPEUM * NRTSM*(1-DCONDM)*DURCM)
              + (QPESH*NRTSH*(1-DCONDH)*DURCH))
              + TUMAH*((QPESL*NRTSL*(1-DCONDL)*DURCL)
              + (QPESM*NRTSM*(1-DCONDM)*DURCM)
              + (QPEUH*NRTSH*(1-DCONDH)*DURCH));

DRTC     =    DRTCS + DRTCU;

MHMA     =    MHRE  +  MHIE + MHTE + MHTB;

MCOST    =    (TSMA + TUMA)*MHMA*CMH;

TMALC    =    (MHMA * (TSMA + TUMA) + (TSMA*MHSMA) + (TUMA*MHUMA))*CMH;

EXPMS    =    TSMA *(EXPSL+EXPSM+EXPSH);

EXPMU    =    (TUMAL *(EXPUL+EXPSM+EXPSH))+ (TUMAM * (EXPSL+EXPUM+EXPSH))
              + (TUMAH * (EXPSL+EXPSM+EXPUH));

EXPM     =    EXPMS + EXPMU;

EXAS     =    EXPSL + EXPSM + EXPSH;

EXAU     =    EXPUL + EXPUM + EXPUH;

EXM      =    EXPM/(TSMA+TUMA);

TOTL     =    QPESL * ( TSMA +TUMAM+TUMAH)+ (QPEUL*TUMAL);

TOTM     =    QPESM * ( TSMA +TUMAL+TUMAH)+ (QPEUM*TUMAM);

TOTH     =    QPESH * ( TSMA +TUMAL+TUMAM)+ (QPEUH*TUMAH);

TR       =    TOTL + TOTM + TOTH;
TRR      =    TR/(TSMA+TUMA);

TOTLRB   =    TOTL * RTSL;
TOTLRD   =    TOTL * NRTSL*(1-DCONDL);

TOTMRB   =    TOTM * RTSM;
TOTMRD   =    TOTM * NRTSM*(1-DCONDM);

TOTHRB   =    TOTH * RTSH;
TOTHRD   =    TOTH * NRTSH*(1-DCONDH);

TRB      =    TOTLRB + TOTMRB + TOTHRB;
TRD      =    TOT'RD + TOTMRD + TOTHRD;

BRT      =    TRB/TR;
DRT      =    TRD/TR;

BURC     =    BRTC/TRB;
DURC     =    DRTC/TRD;
```

```
TEXPRBS =     TSMA * ((QPESL*RTSL*EXPRBL)+(QPESM*RTSM*EXPRBM)
              + (QPESH*RTSH*EXPRBH));

TEXPRDS =     TSMA * ((QPESL*NRTSL*(1-DCONDL)*EXPRDL)
              + (QPESM*NRTSM*(1-DCONDM)*EXPRDM)
              + (QPESH*NRTSH*(1-DCONDH)*EXPRDH));

TEXPRBU =     TUMAL *((QPEUL*RTSL*EXPRBL)
              + (QPESM*RTSM*EXPRBM) +(QPESH*RTSH*EXPRBH))
              + TUMAM *((QPESL*RTSL*EXPRBL)
              + (QPEUM*RTSM*EXPRBM)+(QPESH*RTSH*EXPRBH))
              + TUMAH*((QPESL*RTSL*EXPRBL)+(QPESM*RTSM*EXPRBM)
              + (QPEUH*RTSH*EXPRBH));

TEXPRDU =     TUMAL *((QPEUL*NRTSL*(1-DCONDL)*EXPRDL)
              + (QPESM*NRTSM*(1-DCONDM)*EXPRDM)
              + (QPESH*NRTSH*(1-DCONDH)*EXPRDH))
              + TUMAM * ((QPESL*NRTSL*(1-DCONDL)*EXPRDL)
              + (QPEUM*NRTSM*(1-DCONDM)*EXPRDM)
              + (QPESH*NRTSH*(1-DCONDH)*EXPRDH))
              + TUMAH*((QPESL*NRTSL*(1-DCONDL)*EXPRDL)
              + (QPESM*NRTSM*(1-DCONDM)*EXPRDM)
              + (EXPUH*NRTSH*(1-DCONDH)*EXPRDH));

TEXPR   =     TEXPRBS + TEXPRDS+ TEXPRBU + TEXPRDU;

EXPRB   =     EXPRBL + EXPRBM  + EXPRBH;

EXPRD   =     EXPRDL + EXPRDM  + EXPRDH;

EXPR    =     TEXPR/(TSMA+TUMA);

EXPPR   =     TEXPR/(TRB+TRD);

CONDS   =     (TSMA*QPESL*((1-RTSL-NRTSL)+(NRTSL*DCONDL))*ACONDL)
              + (TSMA*QPESM*((1-RTSM-NRTSM)+(NRTSM*DCONDM))*ACONDM)
              + (TSMA*QPESH*((1-RTSH-NRTSH)+(NRTSH*DCONDH))*ACONDH);

CONDU   =     (TUMAL*QPEUL*((1-RTSL-NRTSL)+(NRTSL*DCONDL))*ACONDL)
              + (TUMAL*QPESM*((1-RTSM-NRTSM)+(NRTSM*DCONDM))*ACONDM)
              + (TUMAL*QPESH*((1-RTSH-NRTSH)+(NRTSH*DCONDH))*ACONDH)
              + (TUMAM*QPESL*((1-RTSL-NRTSL)+(NRTSL*DCONDL))*ACONDL)
              + (TUMAM*QPEUM*((1-RTSM-NRTSM)+(NRTSM*DCONDM))*ACONDM)
              + (TUMAM*QPESH*((1-RTSH-NRTSH)+(NRTSH*DCONDH))*ACONDH)
              + (TUMAH*QPESL*((1-RTSL-NRTSL)+(NRTSL*DCONDL))*ACONDL)
              + (TUMAH*QPESM*((1-RTSM-NRTSM)+(NRTSM*DCONDM))*ACONDM)
              + (TUMAH*QPEUH*((1-RTSH-NRTSH)+(NRTSH*DCONDH))*ACONDH);

TCONST  =     CONDU + CONDS;

COSTFU  =     (TSMA+TUMA) * (FUELTP + FUELTC) * FUEL;
```

```
TMCS     =   (MCOST/TSMA) + (EXAS + MHSMA *CMH);

TMCU     =   (MCOST/TUMA) + (EXAU + MHUMA *CMH);

TMCM     =   ((TMCS * TSMA)+ (TMCU *TUMA))/ (TSMA + TUMA);

TURCB    =   BURC + EXPRB;

TURCD    =   DURC + EXPRD;

URC      =   ((TURCB * TRB)+ ( TURCD * TRD )) / (TRB + TRD);

CONDR    =   TCONST /(TRB+TRD);

TOTCOST =    BRTC + DRTC + TMALC + EXPM + TEXPR + TCONST + COSTFU;

FILE RESULTS2;

PUT REP AFH MTBFL MTBFM MTBFH SMI QPESL QPESM QPESH QPEUL QPEUM QPEUH
RTSL RTSM RTSH NRTSL NRTSM NRTSH DCONDL DCONDM DCONDH BURCL BURCM
BURCH DURCL DURCM DURCH MHRE MHIE MHTE MHTB MHSMA MHUMA EXPSL EXPSM
EXPSH EXPUL EXPUM EXPUH EXPRBL EXPRBM EXPRBH EXPRDL EXPRDM EXPRDH
ACONDL ACONDM ACONDH FUELTP FUELTC FUEL CMH MCOST TUMA TSMA MTBF NMA
EXAS EXAU EXM EXPRB EXPRD EXPR TCONST TOTL TOTM TOTH TOTLRB TOTLRD
TOTMRB TOTMRD TOTHRB TOTHRD TR TRR TRB TRD BRT DRT BURC DURC TMCS TMCU
TMCM TURCB TURCD URC CONDR EXPPR TOTCOST;
END;
```

Appendix C: Thesis Database

OBS	TOTCOST	NMA	TSMA	BRT	DRT	SQEXPPR	RECITRR	MTBF
1	711350	0.72944	0.357650	0.701726	0.210205	99.534	0.0108632	3759.54
2	1019614	0.83308	0.393829	0.493959	0.391093	109.681	0.0109529	3530.16
3	638735	0.71898	0.347266	0.631860	0.270265	85.534	0.0090467	3058.45
4	629978	0.62063	0.305708	0.508911	0.362478	93.789	0.0087711	3984.78
5	1263076	0.82759	0.362867	0.540207	0.355263	134.958	0.0118427	2768.28
6	886556	0.67772	0.295857	0.603341	0.317743	129.471	0.0129624	3848.67
7	1397821	0.87352	0.392239	0.579252	0.307270	129.308	0.0105032	3775.34
8	767661	0.61781	0.294983	0.521322	0.388857	117.838	0.0117710	3595.51
9	768213	0.71235	0.356467	0.581623	0.298276	87.790	0.0081588	4009.97
10	2018565	0.94857	0.402838	0.528883	0.367365	154.757	0.0110302	3565.49
11	983400	0.75044	0.335654	0.504027	0.364981	134.767	0.0135689	3476.06
12	581691	0.69098	0.346093	0.635250	0.255702	94.584	0.0106320	3392.08
13	841063	0.95916	0.435379	0.608410	0.281484	97.708	0.0113084	3576.35
14	784773	0.62658	0.289976	0.481968	0.372017	141.260	0.0156320	3417.22
15	767055	0.85753	0.386009	0.610684	0.270151	77.757	0.0076524	3919.72
16	650921	0.61787	0.282141	0.561357	0.345112	101.037	0.0102470	3514.76
17	697351	0.65505	0.286108	0.626016	0.255511	98.818	0.0098534	3645.23
18	694371	0.80702	0.414149	0.638369	0.274919	84.851	0.0091896	4084.36
19	702501	0.94110	0.465964	0.549878	0.338500	73.109	0.0084124	4210.11
20	1030152	0.80722	0.339364	0.624515	0.266772	100.304	0.0085476	3447.06
21	846346	0.84836	0.408749	0.528260	0.354694	107.726	0.0126588	3129.38
22	521133	0.66305	0.346578	0.620180	0.276583	79.218	0.0086765	4243.07
23	1024593	1.03968	0.524020	0.593036	0.280987	90.900	0.0092027	4081.07
24	980503	0.89907	0.438820	0.562466	0.336988	99.459	0.0096251	3772.94
25	852709	0.73687	0.299789	0.583024	0.260410	103.500	0.0091816	2994.69
26	963372	0.66316	0.279785	0.605410	0.301449	135.768	0.0128779	3154.67
27	1228062	0.95112	0.425044	0.629023	0.273225	112.645	0.0103602	3409.82
28	627442	0.67839	0.338740	0.594148	0.294293	96.948	0.0103579	3625.45
29	1003328	0.78834	0.372618	0.667984	0.238689	107.384	0.0090944	3284.68
30	1064978	0.87106	0.424302	0.662645	0.241065	114.040	0.0108399	3952.93
31	803755	0.70558	0.370721	0.558621	0.313500	115.535	0.0119516	3339.11
32	588800	0.88469	0.415783	0.590055	0.275771	84.094	0.0111202	3369.99

OBS	TOTCOST	NMA	TSMA	BRT	DRT	SQEXPPR	RECITRR	MTBF
33	1065803	0.70098	0.320690	0.594962	0.304156	119.491	0.0094829	3117.17
34	1153114	0.80248	0.351693	0.577556	0.312568	117.907	0.0095980	3869.49
35	963130	0.81875	0.407247	0.580678	0.327943	107.861	0.0104912	3773.38
36	643108	0.50780	0.247374	0.584887	0.320053	113.555	0.0105190	3854.22
37	733366	0.65666	0.336647	0.581703	0.325553	107.086	0.0110795	4100.37
38	685749	0.61937	0.300235	0.662813	0.233533	115.938	0.0121116	3842.33
39	828532	0.96263	0.444318	0.587165	0.302437	80.872	0.0080649	3444.34
40	1196395	0.82692	0.428392	0.621105	0.277584	132.193	0.0120116	4233.21
41	653273	0.67413	0.287846	0.554478	0.349839	97.067	0.0109477	3574.04
42	1202105	0.93791	0.457885	0.574463	0.290293	115.072	0.0103818	3602.26
43	962874	0.77113	0.358117	0.491859	0.355250	117.426	0.0108718	4115.42
44	451400	0.52267	0.268320	0.563338	0.319716	80.595	0.0086167	4930.48
45	749723	0.90356	0.430144	0.523590	0.347365	105.022	0.0134651	3476.24
46	1222568	0.69629	0.306127	0.498730	0.331478	143.174	0.0104789	3392.47
47	829674	0.68317	0.353538	0.615704	0.298879	100.450	0.0091981	4046.34
48	508900	0.72676	0.316499	0.699896	0.221522	84.765	0.0111076	3759.98
49	962011	0.73008	0.361953	0.606239	0.288013	143.732	0.0158350	2938.57
50	525486	0.69408	0.336297	0.552143	0.331044	76.189	0.0087309	3596.80
51	930419	0.66570	0.289412	0.564955	0.330536	101.543	0.0073943	3522.08
52	485187	0.62584	0.279037	0.556375	0.333601	80.388	0.0096717	3876.30
53	840659	0.60119	0.254877	0.556269	0.324916	105.393	0.0086390	3556.17
54	1042134	0.83312	0.377482	0.549307	0.342786	112.437	0.0105524	3853.27
55	640311	0.81020	0.362666	0.568520	0.318342	89.735	0.0106569	3408.20
56	427409	0.80186	0.392000	0.714707	0.224225	60.382	0.0083650	3366.76
57	756221	0.71267	0.342318	0.515807	0.326349	89.660	0.0077382	3421.10
58	427889	0.70204	0.336845	0.586200	0.295566	71.715	0.0102422	3287.54
59	751988	0.71749	0.331415	0.500496	0.399550	92.453	0.0091321	3104.67
60	941455	0.85344	0.425191	0.561803	0.327350	102.859	0.0097079	3411.30
61	1115257	0.79552	0.291625	0.506421	0.351675	128.948	0.0118694	2933.08
62	1019931	0.62373	0.268525	0.586484	0.298410	138.392	0.0115453	3790.81
63	693131	0.84232	0.438212	0.653615	0.239729	97.438	0.0122055	4141.37
64	1812890	1.03270	0.466284	0.536637	0.343853	128.774	0.0093274	3239.29

OBS	TOTCOST	NMA	TSMA	BRT	DRT	SQEXPPR	RECITRR	MTBF
65	606429	0.66151	0.301857	0.584817	0.295236	98.396	0.0114135	2885.66
66	937526	0.77571	0.354428	0.614666	0.305306	105.009	0.0095716	3041.70
67	1112055	0.79442	0.393617	0.568693	0.344682	126.146	0.0118108	3614.54
68	1538917	0.97853	0.467191	0.480908	0.381837	116.667	0.0089283	3873.42
69	485410	0.83023	0.458782	0.600660	0.280799	77.775	0.0116363	4007.21
70	626968	0.64627	0.293805	0.523430	0.320307	83.494	0.0083657	3523.73
71	839606	0.80685	0.377101	0.604517	0.305538	96.340	0.0094027	3023.98
72	811522	0.70881	0.285217	0.638732	0.251533	111.726	0.0107717	3094.87
73	975977	0.65915	0.288004	0.588554	0.336589	127.378	0.0114902	3489.97
74	462264	0.59148	0.277260	0.620700	0.288062	82.086	0.0104397	4096.61
75	1316265	0.90058	0.427085	0.654351	0.258640	132.879	0.0120061	3510.32
76	1120173	1.14364	0.556190	0.469091	0.406365	98.102	0.0100332	2845.64
77	937718	0.82858	0.401062	0.563834	0.332823	121.410	0.0132413	3251.55
78	463403	0.67902	0.363349	0.576990	0.304595	71.156	0.0097329	4261.95
79	963425	0.92262	0.420377	0.559152	0.341899	117.209	0.0134469	3340.76
80	628033	0.66215	0.313298	0.553089	0.345533	100.903	0.0115848	4093.11
81	886951	0.72445	0.340478	0.550861	0.345323	99.038	0.0087445	3934.12
82	1416011	0.98437	0.481941	0.639660	0.245767	133.374	0.0118035	3259.74
83	412961	0.52780	0.293652	0.648698	0.268813	82.625	0.0100738	4689.45
84	1065953	0.71359	0.270792	0.520175	0.378324	130.045	0.0116199	3775.86
85	580798	0.80810	0.438212	0.581606	0.315293	75.760	0.0098181	4381.16
86	1643417	1.16687	0.517632	0.583219	0.307050	108.257	0.0085128	2942.97
87	772441	0.90720	0.423728	0.506781	0.324660	106.979	0.0129605	3531.15
88	683074	0.71544	0.310353	0.526282	0.336568	93.702	0.0099482	3805.80
89	904585	0.78545	0.338628	0.652861	0.259101	94.727	0.0079823	3173.43
90	597433	0.72009	0.353005	0.606962	0.302107	92.637	0.0112148	3309.70
91	487968	0.55807	0.289400	0.507608	0.355425	101.806	0.0117767	3835.14
92	909327	0.81796	0.374781	0.555945	0.308786	121.174	0.0131503	3282.43
93	799853	0.56137	0.254753	0.512798	0.354130	128.616	0.0111756	3232.79
94	1049482	0.87630	0.386855	0.572676	0.341980	111.634	0.0110094	3267.32
95	1524899	1.07291	0.479911	0.515799	0.363228	114.102	0.0096929	3074.98
96	624423	0.70662	0.354025	0.630115	0.285369	94.205	0.0118036	3900.74

OBS	TOTCOST	NMA	TSMA	BRT	DRT	SQEXPPR	RECITRR	MTBF
97	1622290	1.07627	0.425410	0.473761	0.370460	129.628	0.0107018	3657.62
98	1232530	0.99029	0.441712	0.644833	0.272420	119.448	0.0117035	3268.74
99	757389	0.90173	0.408116	0.522456	0.373296	80.614	0.0084684	4084.81
100	973802	0.82550	0.417494	0.550685	0.331426	113.836	0.0112119	3319.03
101	804699	0.70264	0.325767	0.674640	0.249112	107.006	0.0102902	3336.96
102	696107	0.83194	0.386269	0.614009	0.297405	89.076	0.0105868	3864.91
103	1302786	0.66094	0.300559	0.513814	0.380607	132.319	0.0090898	3712.70
104	725350	0.79638	0.372858	0.646416	0.253509	95.224	0.0107722	4344.76
105	783103	0.81247	0.366976	0.675943	0.247207	92.244	0.0096081	3925.40
106	1073156	0.90303	0.447326	0.516563	0.308477	130.749	0.0135385	4032.94
107	737468	0.66006	0.291385	0.516260	0.382419	103.450	0.0101038	3172.17
108	655832	0.64634	0.290075	0.588230	0.305221	84.426	0.0075907	3867.32
109	1268291	0.84342	0.344127	0.616003	0.268120	109.283	0.0079312	3475.18
110	1127843	0.79685	0.375931	0.651316	0.273976	118.810	0.0103885	3168.16
111	1327374	0.66261	0.287491	0.576520	0.290521	139.964	0.0092513	3252.15
112	1002269	1.04035	0.484266	0.685685	0.238779	105.299	0.0118396	3752.02
113	584518	0.72122	0.375412	0.614527	0.283235	86.261	0.0103271	3756.19
114	1058972	0.83609	0.435673	0.622140	0.284444	115.418	0.0112303	3909.45
115	456871	0.80100	0.425574	0.500755	0.383002	75.965	0.0128119	4044.30
116	1511577	0.90242	0.357003	0.611288	0.292096	138.636	0.0116305	2697.81
117	627087	0.89796	0.493143	0.625271	0.288758	77.863	0.0106512	3926.99
118	918402	0.68630	0.281103	0.638457	0.267354	129.467	0.0121785	2939.58
119	1113275	0.98978	0.446022	0.621897	0.276024	113.720	0.0121107	2998.41
120	446264	0.79157	0.413414	0.503791	0.356493	74.613	0.0116309	3740.45
121	927779	0.79067	0.365758	0.560640	0.325005	114.249	0.0112482	3930.68
122	877021	0.59378	0.263795	0.532920	0.328772	123.608	0.0102230	4423.95
123	1061306	0.63508	0.245387	0.551151	0.339255	117.174	0.0084918	3375.68
124	552322	0.57922	0.271726	0.576264	0.302937	109.832	0.0129210	4291.38
125	1409692	1.10402	0.499962	0.502100	0.362857	115.391	0.0108808	3402.56
126	705307	0.74661	0.346362	0.539340	0.315308	105.214	0.0118120	3234.46
127	1586203	0.83385	0.351450	0.589091	0.295918	131.503	0.0089158	3550.39
128	1044155	0.72385	0.351595	0.585059	0.322243	123.322	0.0110576	3276.36

OBS	TOTCOST	NMA	TSMA	BRT	DRT	SQEXPPR	RECITRR	MTBF
129	1047426	0.70395	0.272443	0.686039	0.244195	122.977	0.0104166	3614.94
130	680927	0.66518	0.282596	0.539840	0.320095	88.040	0.0082350	3288.57
131	934781	0.69279	0.331586	0.481334	0.386713	100.109	0.0078810	4024.43
132	1149313	0.79909	0.374080	0.510296	0.380200	119.542	0.0098620	3698.63
133	1959612	0.88896	0.343654	0.570265	0.307047	149.760	0.0095471	3755.58
134	755249	0.57019	0.255773	0.587424	0.308884	114.114	0.0100135	3622.75
135	656471	0.66696	0.310659	0.559568	0.350752	94.533	0.0099522	3522.84
136	1086276	0.81014	0.323403	0.607911	0.311190	142.565	0.0154474	2934.24
137	973661	0.72831	0.356374	0.554818	0.351544	112.331	0.0100186	3188.38
138	892552	0.68176	0.312811	0.670404	0.243272	101.219	0.0084613	3795.71
139	1163319	0.79189	0.379730	0.532140	0.338645	154.740	0.0155632	3182.88
140	1126487	0.91742	0.442361	0.707594	0.224164	128.764	0.0137130	3588.11
141	1095935	0.89561	0.400843	0.496295	0.350719	99.486	0.0085501	3065.56
142	853554	0.65933	0.269383	0.610777	0.280621	110.167	0.0095582	3525.86
143	724020	0.73878	0.394604	0.610918	0.295499	95.853	0.0099658	3310.35
144	579889	0.86233	0.438992	0.525142	0.341455	79.464	0.0102085	3391.44
145	500594	0.66412	0.333806	0.570758	0.309829	90.834	0.0118135	4056.86
146	524701	0.59151	0.320264	0.497791	0.373360	83.061	0.0091044	4588.85
147	680132	0.74336	0.349238	0.535109	0.342991	104.530	0.0124655	4285.40
148	675123	0.75100	0.385005	0.658081	0.236825	91.667	0.0102448	3965.85
149	957798	0.95409	0.474580	0.555461	0.355514	93.738	0.0094140	3642.58
150	686052	0.64933	0.275934	0.528189	0.355106	111.975	0.0117121	3894.61
151	867940	0.77815	0.322481	0.630278	0.281294	115.522	0.0122573	2802.43
152	1178637	0.84339	0.352431	0.584230	0.306494	113.685	0.0093120	3959.27
153	871328	0.78432	0.396578	0.571524	0.305294	96.832	0.0092160	3452.33
154	1425892	0.88460	0.387587	0.549162	0.322254	156.661	0.0144719	3199.92
155	777504	0.70195	0.338635	0.630422	0.279802	109.803	0.0114386	3087.51
156	1804807	0.85044	0.367014	0.485246	0.393938	139.281	0.0091253	3635.48
157	640220	0.66618	0.324787	0.500552	0.394145	94.829	0.0104823	3426.52
158	1116454	0.88990	0.446958	0.518910	0.318682	107.797	0.0090527	3141.73
159	533459	0.52545	0.222350	0.559332	0.283596	116.978	0.0131226	3733.98
160	889119	0.75377	0.337736	0.603321	0.275908	105.212	0.0093631	3146.87

OBS	TOTCOST	NMA	TSMA	BRT	DRT	SQEXPPR	RECITRR	MTBF
161	958957	0.78414	0.404905	0.568855	0.322786	104.180	0.0088655	3817.77
162	911349	0.82332	0.382884	0.498204	0.379641	110.600	0.0116604	3377.91
163	1272278	0.80121	0.415593	0.573450	0.331530	112.636	0.0080767	3601.94
164	1041979	0.98874	0.457991	0.531550	0.349966	93.767	0.0093060	3917.15
165	648496	0.72115	0.343225	0.698368	0.214126	98.206	0.0110858	3553.97
166	1117458	0.74512	0.367224	0.499194	0.358691	110.730	0.0082831	4060.33
167	761945	0.86431	0.450545	0.656499	0.245077	95.573	0.0107811	3224.26
168	535927	0.68377	0.313506	0.548868	0.342425	76.749	0.0089033	3032.50
169	763671	0.73519	0.347647	0.560290	0.345331	114.661	0.0133545	3433.76
170	1443072	1.11733	0.552610	0.571626	0.294359	110.957	0.0094143	3648.89
171	1145432	0.85616	0.388495	0.564962	0.327371	146.545	0.0157843	4075.55
172	790800	0.66498	0.273857	0.626236	0.246782	114.319	0.0108904	3109.74
173	733221	0.82587	0.412036	0.535556	0.334193	91.592	0.0100118	3741.59
174	1040746	0.86132	0.410303	0.721161	0.211994	106.219	0.0096141	3787.06
175	727745	0.67666	0.288018	0.648484	0.258237	106.516	0.0115057	2877.78
176	949909	0.90571	0.415238	0.565558	0.307036	106.327	0.0110801	3195.72
177	753599	0.67536	0.345696	0.517864	0.363160	101.347	0.0098825	3231.21
178	493493	0.52043	0.234274	0.567805	0.339241	107.856	0.0128430	3450.24
179	1199337	0.74039	0.308306	0.559950	0.330017	125.947	0.0096557	3771.95
180	687226	0.63294	0.299299	0.468325	0.431327	96.521	0.0095247	3724.56
181	588767	0.71935	0.317174	0.640775	0.279225	85.844	0.0102239	3643.51
182	1229115	0.63762	0.289332	0.587693	0.295851	132.349	0.0088525	3299.91
183	1003184	0.85434	0.404891	0.548594	0.324069	115.941	0.0115321	3522.94
184	1059270	1.01252	0.554786	0.559313	0.312907	104.133	0.0109122	4006.02
185	735302	0.63081	0.271792	0.581188	0.306255	119.219	0.0117182	4068.62
186	843536	0.66171	0.317505	0.548274	0.344532	113.208	0.0103344	3763.14
187	1475576	0.75005	0.346495	0.568862	0.353938	144.785	0.0104806	3721.40
188	1087521	0.74979	0.331586	0.633586	0.271760	155.781	0.0162619	3761.41
189	736054	0.65396	0.283604	0.598710	0.264093	104.954	0.0092405	3906.22
190	1043808	0.81565	0.385618	0.567652	0.341955	118.022	0.0109859	3150.07
191	993144	0.71833	0.290846	0.603465	0.280571	138.092	0.0135334	2954.17
192	1108875	0.89108	0.371820	0.541618	0.354200	120.058	0.0115407	3265.02

OBS	TOTCOST	NMA	TSMA	BRT	DRT	SQEXPPR	RECITRR	MTBF
193	712963	0.61030	0.300068	0.585394	0.294744	112.085	0.0110717	3622.17
194	656943	0.86297	0.396830	0.614519	0.281233	78.009	0.0091511	3227.33
195	637637	0.59577	0.292559	0.629256	0.276232	97.106	0.0092393	4649.05
196	476478	0.57342	0.272857	0.652439	0.230132	84.503	0.0087963	3887.97
197	547909	0.67699	0.286067	0.700918	0.234505	85.470	0.0101692	2948.61
198	854974	0.79477	0.415946	0.553242	0.333823	101.232	0.0101098	3982.28
199	821327	0.86788	0.458749	0.627668	0.280165	90.362	0.0097258	3729.85
200	933106	0.71542	0.318406	0.587454	0.272485	112.265	0.0096552	3954.94
201	1191868	0.81936	0.361093	0.620366	0.296365	118.235	0.0099759	3529.71
202	731853	0.67091	0.312682	0.608669	0.284960	103.602	0.0099663	3354.01
203	919723	0.73055	0.296388	0.630755	0.279481	105.303	0.0092921	3216.64
204	873597	0.83139	0.425864	0.605197	0.280568	98.619	0.0098879	3331.53
205	1328879	0.98248	0.457737	0.621696	0.287925	130.213	0.0125421	3939.55
206	1584614	0.99393	0.442776	0.536322	0.309739	137.640	0.0110777	3187.32
207	678944	0.70322	0.361445	0.693549	0.218417	87.557	0.0085367	4231.09
208	383217	0.56069	0.268098	0.664566	0.251310	71.336	0.0090265	3490.46
209	1748774	0.85582	0.341238	0.452124	0.407580	151.769	0.0108623	3410.87
210	968225	0.83189	0.433033	0.560892	0.318516	119.143	0.0122672	4019.55
211	1133833	0.85562	0.394860	0.596628	0.306891	110.896	0.0097121	3560.72
212	659538	0.76368	0.348200	0.654670	0.262108	90.956	0.0108117	3239.19
213	1065879	0.82474	0.366423	0.622215	0.256878	118.706	0.0107400	3201.64
214	937423	0.77709	0.347258	0.641482	0.246959	117.349	0.0114578	3423.15
215	611546	0.82230	0.452228	0.483076	0.377479	78.361	0.0097568	3959.36
216	465601	0.61010	0.327681	0.543252	0.318766	76.383	0.0086485	4061.21
217	956514	0.82064	0.388927	0.584611	0.330072	101.774	0.0099468	3457.74
218	1780092	0.95280	0.365917	0.588188	0.294156	145.335	0.0109272	2991.98
219	1073221	0.70969	0.321269	0.498564	0.392238	113.231	0.0091023	3482.32
220	602553	0.73430	0.384726	0.554467	0.350495	89.619	0.0106190	3355.42
221	512784	0.49723	0.246450	0.637251	0.275374	101.539	0.0103785	4067.81
222	716417	0.94520	0.478037	0.645479	0.268745	89.112	0.0115174	3657.66
223	986708	0.82010	0.376921	0.598882	0.315543	106.756	0.0097106	2901.82
224	686660	0.79449	0.374707	0.646304	0.279425	95.556	0.0111812	4448.43

OBS	TOTCOST	NMA	TSMA	BRT	DRT	SQEXPPR	RECITRR	MTBF
225	644441	0.75785	0.363877	0.617464	0.287581	93.156	0.0110954	4288.40
226	610154	0.73120	0.372192	0.532779	0.330811	76.696	0.0081380	4058.84
227	826581	0.77345	0.390147	0.609128	0.285533	112.626	0.0118551	3616.01
228	601762	0.72135	0.377262	0.522144	0.351103	106.921	0.0143275	3740.95
229	758735	0.85204	0.426577	0.663155	0.263263	85.492	0.0093204	3520.09
230	617980	0.63517	0.282638	0.570397	0.322389	91.807	0.0092793	3402.79
231	591101	0.71950	0.321906	0.648196	0.230983	86.978	0.0096708	3568.51
232	703177	0.66059	0.340064	0.635126	0.260169	97.350	0.0092548	3656.79
233	1256893	0.74901	0.293398	0.542585	0.349736	114.738	0.0078753	2939.30
234	845282	0.72240	0.312220	0.455799	0.404100	106.747	0.0105899	2843.47
235	518413	0.72686	0.349331	0.662038	0.264421	79.222	0.0101190	3359.36
236	951201	0.72686	0.341388	0.641211	0.260765	126.005	0.0120892	3687.84
237	565357	0.81091	0.412514	0.605631	0.242980	87.735	0.0112705	3653.16
238	724638	1.11953	0.579672	0.577337	0.321054	73.161	0.0090543	3186.55
239	747959	0.73888	0.402027	0.528410	0.322981	106.997	0.0112426	3806.02
240	612958	0.93670	0.499558	0.600280	0.299371	91.023	0.0140729	4166.98
241	589803	0.60361	0.281329	0.546188	0.345310	91.515	0.0090958	4127.24
242	1185499	0.63899	0.251820	0.586362	0.302443	149.258	0.0116396	3418.63
243	562473	0.63141	0.296505	0.500622	0.356834	92.882	0.0100165	3341.07
244	918802	0.75178	0.332160	0.564248	0.321432	100.966	0.0083741	2857.75
245	1640519	0.78409	0.317834	0.505560	0.343334	176.238	0.0136772	3221.52
246	452791	0.55891	0.247169	0.629958	0.296127	77.157	0.0087969	4055.70
247	893291	0.90925	0.467447	0.569437	0.326110	94.053	0.0100623	4334.08
248	1092851	1.14898	0.518086	0.549496	0.345926	97.748	0.0111485	3193.05
249	1447030	0.79411	0.297919	0.579193	0.339324	144.847	0.0114618	3392.14
250	848263	0.71647	0.342524	0.577317	0.281204	105.342	0.0093399	3572.21

Appendix D: Outlier Statistics

OBS	SRESID	LEVERAGE	COOKD
1	0.4066	0.0263583	0.000559
2	0.4509	0.0196528	0.000509
3	0.2234	0.0253819	0.000162
4	-1.0065	0.0235220	0.003050
5	-0.0990	0.0285435	0.000036
6	-1.0297	0.0311139	0.004256
7	0.8695	0.0175330	0.001687
8	-0.7192	0.0370938	0.002491
9	0.5376	0.0185283	0.000682
10	4.1406	0.0481957	0.108516
11	-0.8646	0.0259164	0.002486
12	-0.0534	0.0190310	0.000007
13	-1.2677	0.0253137	0.005217
14	-0.2180	0.0650025	0.000413
15	-0.7140	0.0377093	0.002497
16	-0.4488	0.0179192	0.000459
17	0.2652	0.0203317	0.000182
18	-0.6269	0.0207945	0.001043
19	-1.6586	0.0394756	0.014132
20	0.4977	0.0229407	0.000727
21	0.5274	0.0245153	0.000874
22	0.0967	0.0229639	0.000027
23	-0.7885	0.0419548	0.003404
24	-0.8045	0.0153443	0.001261
25	-0.4438	0.0586176	0.001533
26	-0.6567	0.0254714	0.001409
27	0.4863	0.0179223	0.000539
28	-0.2984	0.0095292	0.000107
29	-0.3133	0.0258831	0.000326
30	-0.2256	0.0252186	0.000165
31	0.1034	0.0302105	0.000042
32	-0.5062	0.0347455	0.001153
33	-0.2468	0.0220713	0.000172
34	-0.5626	0.0156901	0.000631
35	-0.3251	0.0143301	0.000192
36	-1.0106	0.0282331	0.003709
37	-0.0185	0.0204147	0.000001
38	-0.1984	0.0287819	0.000146
39	-2.0809	0.0289044	0.016111
40	-0.0527	0.0460344	0.000017
41	0.3601	0.0261414	0.000435
42	0.1255	0.0233508	0.000047
43	-1.0780	0.0303140	0.004541
44	0.9247	0.0596035	0.006774
45	-0.4503	0.0337026	0.000884

OBS	SRESID	LEVERAGE	COOKD
46	-1.6926	0.0548954	0.020802
47	0.1936	0.0245590	0.000118
48	0.6712	0.0437417	0.002576
49	0.8945	0.0688106	0.007392
50	0.3117	0.0182989	0.000226
51	-0.7449	0.0254774	0.001813
52	1.0151	0.0273464	0.003621
53	0.0145	0.0198763	0.000001
54	-0.4675	0.0131072	0.000363
55	-0.7705	0.0183729	0.001389
56	0.0471	0.0522360	0.0000153
57	-0.4544	0.0398151	0.0010703
58	2.1814	0.0313287	0.0192383
59	-0.2552	0.0399712	0.0003390
60	-0.9657	0.0134440	0.0015884
61	-0.4502	0.0496585	0.0013236
62	-1.4603	0.0252518	0.0069057
63	0.2945	0.0326762	0.0003662
64	3.4306	0.0339696	0.0517324
65	1.0960	0.0318075	0.0049330
66	-0.4067	0.0217066	0.0004589
67	-0.0357	0.0266990	0.0000044
68	2.4587	0.0476841	0.0378361
69	1.1884	0.0353251	0.0064644
70	1.0835	0.0401988	0.0061466
71	-0.6569	0.0192928	0.0010612
72	-0.8250	0.0272186	0.0023805
73	-0.7081	0.0284831	0.0018378
74	2.1252	0.0269303	0.0156244
75	0.4046	0.0283774	0.0005976
76	-2.3509	0.0699810	0.0519845
77	-0.1684	0.0210493	0.0000762
78	2.4725	0.0261470	0.0205166
79	-0.5566	0.0293695	0.0011719
80	0.1758	0.0220434	0.0000871
81	-0.1914	0.0160808	0.0000748
82	0.5489	0.0454316	0.0017926
83	1.9726	0.0486210	0.0248585
84	-1.0781	0.0453754	0.0069063
85	0.9694	0.0310464	0.0037635
86	1.8697	0.0563799	0.0261071
87	-0.9280	0.0546175	0.0062198
88	-0.1638	0.0255610	0.0000879
89	-0.7127	0.0281463	0.0018390
90	0.5313	0.0166096	0.0005961
91	0.4508	0.0321873	0.0008447
92	-0.1893	0.0222124	0.0001018
93	-1.9676	0.0340210	0.0170431
94	-0.4173	0.0211606	0.0004706
95	1.7054	0.0360030	0.0135770

OBS	SRESID	LEVERAGE	COOKD
96	1.6337	0.0179173	0.0060870
97	0.6235	0.0906045	0.0048409
98	-0.1272	0.0275005	0.0000572
99	-2.2039	0.0513332	0.0328536
100	-0.2917	0.0176669	0.0001913
101	-0.4786	0.0211367	0.0006182
102	-0.3800	0.0195365	0.0003597
103	0.2728	0.0426143	0.0004141
104	-0.2153	0.0317610	0.0001901
105	-0.6088	0.0274945	0.0013098
106	-0.6637	0.0700753	0.0041488
107	-0.7073	0.0289753	0.0018659
108	-0.3995	0.0229653	0.0004690
109	0.7330	0.0350195	0.0024371
110	0.3448	0.0266771	0.0004072
111	-0.1659	0.0477012	0.000172
112	-1.3864	0.0465037	0.011718
113	0.7933	0.0130109	0.001037
114	0.5185	0.0261851	0.000903
115	2.8273	0.0602520	0.064065
116	1.6285	0.0367704	0.012655
117	0.4573	0.0364454	0.000989
118	-1.1184	0.0284994	0.004586
119	0.1574	0.0273980	0.000087
120	1.8426	0.0422918	0.018740
121	-0.8662	0.0103680	0.000983
122	1.6670	0.0439598	0.015972
123	-0.2949	0.0286706	0.000321
124	0.6083	0.0372927	0.001792
125	0.4675	0.0402756	0.001146
126	-0.0804	0.0250624	0.000021
127	2.1915	0.0284998	0.017611
128	0.1112	0.0217781	0.000034
129	-0.5828	0.0402401	0.001780
130	0.0633	0.0332972	0.000017
131	-0.2045	0.0340351	0.000184
132	-0.8040	0.0211002	0.001742
133	3.7370	0.0596176	0.110667
134	-1.0840	0.0168907	0.002523
135	-0.1696	0.0192208	0.000070
136	0.3125	0.0634540	0.000827
137	-0.0565	0.0262557	0.000011
138	0.2570	0.0253414	0.000215
139	-0.3405	0.0559408	0.000859
140	0.3104	0.0500413	0.000635
141	0.2444	0.0362652	0.000281
142	-0.7469	0.0172283	0.001223
143	-0.0557	0.0293548	0.000012
144	-0.5745	0.0272452	0.001155
145	1.3519	0.0209485	0.004888

OBS	SRESID	LEVERAGE	COOKD
146	0.9146	0.0466051	0.005111
147	-0.0823	0.0331354	0.000029
148	0.4634	0.0210462	0.000577
149	-1.3284	0.0303222	0.006897
150	-1.2284	0.0251642	0.004869
151	-0.2873	0.0321474	0.000343
152	-0.4010	0.0290872	0.000602
153	0.3344	0.0159954	0.000227
154	0.1795	0.0386625	0.000162
155	0.1692	0.0218350	0.000080
156	3.5757	0.0436030	0.072863
157	0.2967	0.0306758	0.000348
158	-0.1549	0.0527239	0.000167
159	0.4014	0.0639452	0.001376
160	-0.6612	0.0173051	0.000962
161	-0.8900	0.0225009	0.002279
162	-0.3056	0.0180374	0.000214
163	0.9159	0.0491707	0.005422
164	-0.6609	0.0327376	0.001848
165	0.1196	0.0250271	0.000046
166	0.1301	0.0355229	0.0000780
167	-0.3532	0.0332057	0.0005356
168	0.7975	0.0346337	0.0028525
169	0.3176	0.0249927	0.0003233
170	0.3113	0.0500314	0.0006381
171	-0.1462	0.0617777	0.0001760
172	-0.5206	0.0338212	0.0011861
173	-0.6906	0.0129047	0.0007794
174	-0.3766	0.0398775	0.0007364
175	0.8017	0.0314495	0.0026084
176	-0.5789	0.0153295	0.0006522
177	0.0264	0.0287226	0.0000026
178	0.9502	0.0392314	0.0046087
179	-0.5890	0.0199482	0.0008828
180	-0.4971	0.0506504	0.0016479
181	0.3782	0.0243220	0.0004458
182	-0.1569	0.0433925	0.0001395
183	-0.5216	0.0093619	0.0003214
184	-0.3792	0.0547632	0.0010412
185	-1.6283	0.0225046	0.0076306
186	-0.8268	0.0130783	0.0011325
187	0.2220	0.0543484	0.0003541
188	-0.3725	0.0646397	0.0011987
189	-1.5297	0.0318459	0.0096218
190	-0.6993	0.0194580	0.0012131
191	-0.5550	0.0344835	0.0013750
192	-1.0742	0.0250687	0.0037088
193	-0.1678	0.0167468	0.0000599
194	-0.5272	0.0248175	0.0008841
195	-0.6027	0.0405054	0.0019166

OBS	SRESID	LEVERAGE	COOKD
196	0.3632	0.0351923	0.0006015
197	0.8755	0.0515056	0.0052034
198	-0.3840	0.0173596	0.0003257
199	-0.0093	0.0233671	0.0000003
200	-0.5640	0.0287789	0.0011782
201	0.2231	0.0159062	0.0001006
202	-0.6156	0.0110680	0.0005302
203	-0.2908	0.0217790	0.0002353
204	0.0691	0.0204364	0.0000125
205	0.0601	0.0354888	0.0000166
206	0.9782	0.0405221	0.0050520
207	-0.1309	0.0380643	0.0000848
208	2.4587	0.0353801	0.0277163
209	1.8184	0.0486758	0.0211488
210	-0.4176	0.0253225	0.0005662
211	0.0945	0.0100270	0.0000113
212	0.6107	0.0212822	0.0010137
213	-0.3673	0.0190098	0.0003269
214	-0.3404	0.0167427	0.0002466
215	0.2686	0.0407109	0.0003827
216	1.1309	0.0317964	0.0052506
217	0.2264	0.0140397	0.0000912
218	2.6191	0.0445692	0.0400000
219	0.1698	0.0262270	0.0000971
220	0.0925	0.0274930	0.0000302
221	-0.0584	0.0295906	0.000013
222	-0.5733	0.0268968	0.001136
223	-0.6498	0.0240062	0.001298
224	-0.7989	0.0422529	0.003519
225	-0.0144	0.0234109	0.000001
226	0.1617	0.0263141	0.000088
227	-0.5401	0.0130822	0.000483
228	1.5967	0.0421363	0.014019
229	-0.2892	0.0244358	0.000262
230	-0.1680	0.0157706	0.000057
231	0.0516	0.0310932	0.000011
232	-0.1495	0.0222890	0.000064
233	0.5946	0.0377994	0.001736
234	0.1411	0.0438283	0.000114
235	0.8248	0.0262305	0.002291
236	-0.5731	0.0177650	0.000743
237	0.3577	0.0490957	0.000826
238	-3.5795	0.0615695	0.105077
239	-0.3706	0.0361590	0.000644
240	1.0370	0.0578594	0.008255
241	-0.5337	0.0230097	0.000839
242	-1.5705	0.0314314	0.010005
243	0.0094	0.0279318	0.000000
244	-0.7232	0.0268017	0.001801
245	-0.1999	0.0627358	0.000334

OBS	SRESID	LEVERAGE	COOKD
246	1.1645	0.0407702	0.007205
247	-0.4889	0.0300589	0.000926
248	-1.3482	0.0578601	0.013954
249	0.1016	0.0449061	0.000061
250	-0.5331	0.0233710	0.000850

Appendix E: Point Estimate Data

Column 1 - observation number (1-250)

Column 2 - TOTCOST figure generated by Model-A

Column 3 - point estimate of TOTCOST called COSTHAT generated by Model-S

Column 4 - the difference of the two (column 2 - column 3)

Column 5 - the difference expressed as a percent of TOTCOST

1	2	3	4	5
OBS	TOTCOST	YHAT	RESID	RESIDPC
1	711350	688922	22428	3.153
2	1019614	994659	24955	2.447
3	638735	626406	12329	1.930
4	629978	685577	-55599	-8.826
5	1263076	1268530	-5454	-0.432
6	886556	943215	-56658	-6.391
7	1397821	1349642	48179	3.447
8	767661	807112	-39450	-5.139
9	768213	738443	29770	3.875
10	2018565	1792748	225817	11.187
11	983400	1031103	-47703	-4.851
12	581691	584646	-2955	-0.508
13	841063	911028	-69964	-8.319
14	784773	796559	-11786	-1.502
15	767055	806206	-39151	-5.104
16	650921	675784	-24863	-3.820
17	697351	682680	14671	2.104
18	694371	729047	-34676	-4.994
19	702501	793368	-90867	-12.935
20	1030152	1002651	27501	2.670
21	846346	817229	29117	3.440
22	521133	515787	5346	1.026
23	1024593	1067739	-43146	-4.211
24	980503	1025130	-44627	-4.551
25	852709	876778	-24069	-2.823
26	963372	999614	-36242	-3.762
27	1228062	1201124	26938	2.194
28	627442	644045	-16603	-2.646
29	1003328	1020615	-17287	-1.723
30	1064978	1077427	-12449	-1.169
31	803755	798061	5694	0.708

1	2	3	4	5
OBS	TOTCOST	YHAT	RESID	RESIDPC
32	588800	616600	-27801	-4.722
33	1065803	1079446	-13643	-1.280
34	1153114	1184315	-31201	-2.706
35	963130	981173	-18043	-1.873
36	643108	698801	-55692	-8.660
37	733366	734388	-1022	-0.139
38	685749	696680	-10931	-1.594
39	828532	943166	-114634	-13.836
40	1196395	1199272	-2877	-0.240
41	653273	633409	19864	3.041
42	1202105	1195173	932	0.577
43	962874	1022214	-59340	-6.163
44	451400	401272	50128	11.105
45	749723	774465	-24742	-3.300
46	1222568	1314555	-91987	-7.524
47	829674	818983	10691	1.289
48	508900	472207	36693	7.210
49	962611	914355	48255	5.013
50	525486	508221	17265	3.285
51	930419	971528	-41109	-4.418
52	485187	429225	55962	11.534
53	840659	839856	803	0.096
54	1042134	1068098	-25964	-2.491
55	640311	682984	-42674	-6.665
56	427409	424845	-2564	0.600
57	756221	781112	-24891	-3.292
58	427889	307868	120020	28.049
59	751988	765967	-13979	-1.859
60	941455	995073	-53618	-5.695
61	1115257	1139789	-24532	-2.200
62	1019931	1100527	-80596	-7.902
63	693131	676939	16192	2.336
64	1812890	1624398	188492	10.397
65	606429	546143	60287	9.941
66	937526	960015	-22489	-2.399
67	1112055	1114024	-1969	-0.177
68	1538917	1404791	134126	8.716
69	485410	420162	65249	13.442
70	626968	567627	59341	9.465
71	839606	875972	-36367	-4.331
72	811522	857008	-45486	-5.605
73	975977	1014995	-39018	-3.998
74	462264	345073	117190	25.351
75	1316265	1293971	22294	1.694
76	1120173	1246911	-126738	-11.314
77	937718	947033	-9314	-0.993
78	463403	327006	136396	29.434
79	963425	994080	-30656	-3.182

1	2	3	4	5
OBS	TOTCOST	YHAT	RESID	RESIDPC
80	628033	618313	-9719	1.548
81	886951	897563	-10612	-1.196
82	1416011	1386031	29980	2.117
83	412961	305402	107559	26.046
84	1065953	1124839	-58886	-5.524
85	580798	527457	53341	9.184
86	1643417	1541890	101527	6.178
87	772441	822883	-50442	-6.530
88	683074	692110	-9037	-1.323
89	904585	943863	-39278	-4.342
90	597433	567978	29455	4.930
91	487968	463178	24790	5.080
92	909327	919791	-10464	-1.151
93	799853	907955	-108103	-13.515
94	1049482	1072562	-23080	-2.199
95	1524899	1431299	93600	6.138
96	624423	533916	90506	14.494
97	1622290	1589054	33236	2.049
98	1232530	1239544	-7014	-0.569
99	757389	877387	-119998	-15.844
100	973802	989966	-16164	-1.660
101	804699	831168	-26469	-3.289
102	696107	717142	-21036	-3.022
103	1302786	1287864	14922	1.145
104	725350	737194	-11844	-1.633
105	783103	816664	-33562	-4.286
106	1073156	1108932	-35776	-3.334
107	737468	776429	-38960	-5.283
108	655832	677909	-22077	-3.366
109	1268291	1228041	40250	3.174
110	1127843	1108830	19013	1.686
111	1327374	1336422	-9048	-0.682
112	1002269	1077947	-75678	-7.551
113	584518	540461	44058	7.537
114	1058972	1030372	28600	2.701
115	456871	303656	153215	33.536
116	1511577	1422229	89348	5.911
117	627087	601993	25094	4.002
118	918402	980022	-61620	-6.710
119	1113275	1104599	8676	0.779
120	446264	345464	100800	22.587
121	927779	975948	-48170	-5.192
122	877021	968137	-91116	-10.389
123	1061306	1077552	-16246	-1.531
124	552322	518956	33365	6.041
125	1409692	1384091	25601	1.816
126	705307	709744	-4437	-0.629
127	1586203	1465456	120747	7.612

1	2	3	4	5
OBS	TOTCOST	YHAT	RESID	RESIDPC
128	1044155	1038005	6150	0.589
129	1047426	1079343	-31917	-3.047
130	680927	677450	3477	0.511
131	934781	946015	-11233	-1.202
132	1149313	1193780	-44467	-3.869
133	1959612	1757033	202579	10.338
134	755249	815330	-60081	-7.955
135	656471	665860	-9388	-1.430
136	1086276	1069368	16908	1.557
137	973661	976777	-3116	-0.320
138	892552	878369	14183	1.589
139	1163319	1181813	-18494	-1.590
140	1126487	1109574	16913	1.501
141	1095935	1082523	13412	1.224
142	853554	894948	-41394	-4.850
143	724020	727089	-3070	-0.424
144	579889	611563	-31674	-5.462
145	500594	425817	74777	14.938
146	524701	474781	49920	9.514
147	680132	684654	-4523	-0.665
148	675123	649491	25632	3.797
149	957798	1030920	-73122	-7.634
150	686052	753852	-67800	-9.883
151	867940	883743	-15803	-1.821
152	1178637	1200726	-22089	-1.874
153	871328	852784	18544	2.128
154	1425892	1416056	9836	0.690
155	777504	768150	9354	1.203
156	1804807	1609328	195479	10.831
157	640220	623893	16327	2.550
158	1116454	1124879	-8425	-0.755
159	533459	511750	21709	4.069
160	889119	925762	-36642	-4.121
161	958957	1008148	-49191	-5.130
162	911349	928276	-16927	-1.857
163	1272278	1222353	49925	3.924
164	1041979	1078312	-36333	-3.487
165	648496	641897	6599	1.018
166	1117458	1110314	7144	0.639
167	761945	781359	-19414	-2.548
168	535927	492122	43805	8.174
169	763671	746139	17533	2.296
170	1443072	1426109	16963	1.176
171	1145432	1153350	-7918	-0.691
172	790800	819408	-28608	-3.618
173	733221	771578	-38357	-5.231
174	1040746	1061375	-20629	-1.982
175	727745	683642	44103	6.060

1	2	3	4	5
OBS	TOTCOST	YHAT	RESID	RESIDPC
176	949909	982023	-32114	-3.381
177	753599	752142	1457	0.193
178	493493	441427	52066	10.551
179	1199337	1231935	-32598	-2.718
180	687226	714300	-27075	-3.940
181	588767	567882	20885	3.547
182	1229115	1237691	-8576	-0.698
183	1003184	1032206	-29022	-2.893
184	1059270	1079878	-20608	-1.945
185	735302	825298	-89996	-12.239
186	843536	889454	-45918	-5.444
187	1475576	1463507	12069	0.818
188	1087521	1107661	-20140	-1.852
189	736054	820196	-84142	-11.432
190	1043808	1082518	-38710	-3.709
191	993144	1023628	-30484	-3.069
192	1108875	1168166	-59291	-5.347
193	712963	722263	-9301	-1.305
194	656943	686046	-29103	-4.430
195	637637	670637	-33000	-5.175
196	476478	456534	19944	4.186
197	547909	500242	47667	8.700
198	854974	876255	-21281	-2.489
199	821327	821838	-511	-0.062
200	933106	964177	-31071	-3.330
201	1191868	1179495	12373	1.038
202	731853	766077	-34224	-4.676
203	919723	935800	-16078	-1.748
204	873597	869772	3825	0.438
205	1328879	1325581	3298	0.248
206	1584614	1531048	53566	3.380
207	678944	686121	-7177	-1.057
208	383217	248224	134993	35.226
209	1748774	1649626	99148	5.670
210	968225	991270	-23045	-2.380
211	1133833	1128576	5257	0.464
212	659538	625765	33773	5.121
213	1065879	1086218	-20339	-1.908
214	937423	956289	-18866	-2.013
215	611546	596841	14705	2.405
216	465601	403392	62208	13.361
217	956514	943950	12564	1.314
218	1780092	1636979	143113	8.040
219	1073221	1063854	9367	0.873
220	602553	597454	5099	0.846
221	512784	516001	-3217	-0.627
222	716417	748034	-31617	-4.413
223	986708	1022593	-35885	-3.637

1	2	3	4	5
OBS	TOTCOST	YHAT	RESID	RESIDPC
224	686660	730363	-43703	-6.365
225	644441	645237	-796	-0.124
226	610154	601232	8921	1.462
227	826581	856574	-29993	-3.629
228	601762	514406	87356	14.517
229	758735	774704	-15969	-2.105
230	617980	627297	-9317	-1.508
231	591101	588259	2841	0.481
232	703177	711440	-8263	-1.175
233	1256893	1224290	32603	2.594
234	845282	837571	7711	0.912
235	518413	472912	45501	8.777
236	951201	982952	-31751	-3.338
237	565357	545858	19500	3.449
238	724638	918476	-193838	-26.750
239	747959	768299	-20340	-2.719
240	612958	556689	56268	9.180
241	589803	619295	-29492	-5.000
242	1185499	1271899	-86400	-7.288
243	562473	561953	520	0.092
244	918802	958685	-39883	-4.341
245	1640519	1651337	-10818	-0.659
246	452791	389034	63758	14.081
247	893291	920206	-26915	-3.013
248	1092851	1166005	-73154	-6.694
249	1447030	1441480	5550	0.384
250	848263	877712	-29450	-3.472

OBS	YHAT	L95	U95	BOUND	BOUNDPC
1	688922	577363	800480	111558	15.6826
2	994659	883466	1105853	111193	10.9054
3	626406	514901	737911	111505	17.4572
4	685577	574173	796981	111404	17.6838
5	1268530	1156853	1380207	111677	8.8417
6	943215	831398	1055031	111817	12.6125
7	1349642	1238564	1460720	111078	7.9465
8	807112	694971	919252	112140	14.6080
9	738443	627311	849575	111132	14.4663
10	1792748	1680009	1905487	112739	5.5851
11	1031103	919568	1142637	111534	11.3417
12	584646	473486	695805	111159	19.1097
13	911028	799526	1022529	111502	13.2572
14	796559	682920	910199	113639	14.4805
15	806206	694032	918379	112174	14.6239
16	675784	564685	786882	111099	17.0679
17	682680	571450	793911	111230	15.9504
18	729047	617791	840303	111256	16.0225
19	793368	681099	905637	112269	15.9813
20	1002651	891279	1114024	111372	10.8113
21	817229	705771	928687	111458	13.1693
22	515787	404414	627161	111374	21.3715
23	1067739	955336	1180142	112403	10.9705
24	1025130	914171	1136088	110958	11.3165
25	876778	763480	990076	113298	13.2868
26	999614	888104	1111124	111510	11.5750
27	1201124	1090025	1312223	111099	9.0467
28	644045	533405	754685	110640	17.6335
29	1020615	909083	1132148	111533	11.1163
30	1077427	965931	1188924	111496	10.4694
31	798061	686293	909828	111768	13.9057
32	616600	504587	728614	112013	19.0240
33	1079446	968120	1190771	111325	10.4452
34	1184315	1073338	1295292	110977	9.6241
35	981173	870271	1092076	110903	11.5148
36	698801	587140	810461	111660	17.3626
37	734388	623153	845623	111235	15.1677
38	696680	584990	808370	111690	16.2873
39	943166	831470	1054863	111697	13.4813
40	1199272	1086650	1311895	112623	9.4135
41	633409	521863	744956	111547	17.0750
42	1195173	1083778	1306568	111395	9.2666
43	1022214	910441	1133988	111773	11.6083
44	401272	287922	514623	113351	25.1109
45	774465	662508	886422	111957	14.9331
46	1314555	1201456	1427654	113099	9.2509
47	818983	707522	930443	111461	13.4343
48	472207	359708	584706	112499	22.1063
49	914355	800513	1028197	113842	11.8264
50	508221	397102	619341	111120	21.1461

OBS	YHAT	L95	U95	BOUND	BOUNDPC
51	971528	860017	1083038	111510	11.9850
52	429225	317613	540837	111612	23.0039
53	839856	728651	951062	111206	13.2284
54	1068098	957263	1178934	110836	10.6355
55	682984	571861	794108	111124	17.3546
56	424845	311889	537801	112956	26.4281
57	781112	668825	893399	112287	14.8485
58	307868	196040	419696	111828	26.1349
59	765967	653671	878263	112296	14.9332
60	995073	884218	1105927	110854	11.7748
61	1139789	1026971	1252606	112818	10.1158
62	1100527	989029	1212026	111498	10.9319
63	676939	565037	788840	111901	16.1443
64	1624398	1512427	1736369	111971	6.1764
65	546143	434289	657997	111854	18.4447
66	960015	848710	1071321	111305	11.8722
67	1114024	1002447	1225601	111577	10.0334
68	1404791	1292079	1517502	112711	7.3241
69	420162	308117	532206	112045	23.0825
70	567627	455319	679935	112308	17.9129
71	875972	764799	987146	111174	13.2412
72	857008	745403	968613	111605	13.7526
73	1014995	903322	1126669	111674	11.4423
74	345073	233484	456663	111589	24.1398
75	1293971	1182303	1405639	111668	8.4837
76	1246911	1133006	1360815	113904	10.1685
77	947033	835763	1058302	111269	11.8660
78	327006	215459	438553	111547	24.0713
79	994080	882358	1105802	111722	11.5963
80	618313	506990	729637	111324	17.7258
81	897563	786565	1008561	110998	12.5146
82	1386031	1273441	1498621	112590	7.9512
83	305402	192640	418164	112762	27.3057
84	1124839	1012252	1237426	112587	10.5621
85	527457	415644	639270	111813	19.2516
86	1541890	1428712	1655068	113178	6.8868
87	822883	709800	935967	113084	14.6398
88	692110	580595	803625	111515	16.3255
89	943863	832207	1055518	111655	12.3433
90	567978	456951	679005	111027	18.5841
91	463178	351303	575052	111875	22.9267
92	919791	808458	1031124	111333	12.2434
93	907955	795981	1019929	111974	13.9993
94	1072562	961286	1183837	111276	10.6029
95	1431299	1319218	1543380	112081	7.3501
96	533916	422818	645015	111099	17.7922
97	1589054	1474057	1704051	114997	7.0886
98	1239544	1127924	1351164	111620	9.0562
99	877387	764479	990294	112908	14.9075
100	989966	878881	1101051	111085	11.4074

OBS	YHAT	L95	U95	BOUND	BOUNDPC
101	831168	719894	942442	111274	13.8281
102	717142	605955	828329	111187	15.9727
103	1287864	1175426	1400303	112438	8.6306
104	737194	625342	849045	111852	15.4204
105	816664	705044	928284	111620	14.2536
106	1108932	995023	1222842	113909	10.6144
107	776429	664728	888129	111701	15.1465
108	677909	566535	789283	111374	16.9821
109	1228041	1116013	1340069	112028	8.8330
110	1108830	997254	1220405	111576	9.8928
111	1336422	1223710	1449135	112712	8.4914
112	1077947	965299	1190595	112648	11.2393
113	540461	429630	651291	110831	18.9610
114	1030372	918823	1141921	111549	10.5337
115	303656	190270	417041	113385	24.8178
116	1422229	1310106	1534351	112123	7.4176
117	601993	489888	714098	112105	17.8771
118	980022	868348	1091697	111675	12.1597
119	1104599	992985	1216214	111615	10.0258
120	345464	233043	457885	112421	25.1916
121	975948	865262	1086634	110686	11.9302
122	968137	855626	1080648	112511	12.8288
123	1077552	965868	1189236	111684	10.5233
124	518956	406805	631108	112151	20.3054
125	1384091	1271778	1496403	112312	7.9671
126	709744	598256	821232	111488	15.8070
127	1465456	1353782	1577131	111675	7.0404
128	1038005	926696	1149314	111309	10.6602
129	1079343	967033	1191653	112310	10.7225
130	677450	565515	789385	111935	16.4386
131	946015	834040	1057989	111975	11.9787
132	1193780	1082507	1305052	111272	9.6816
133	1757033	1643682	1870385	113351	5.7844
134	815330	704287	926373	111043	14.7028
135	665860	554690	777029	111170	16.9344
136	1069368	955811	1182924	113556	10.4537
137	976777	865224	1088329	111553	11.4571
138	878369	766866	989872	111503	12.4926
139	1181813	1068659	1294968	113155	9.7269
140	1109574	996736	1222412	112838	10.0168
141	1082523	970428	1194619	112095	10.2283
142	894948	783887	1006009	111061	13.0116
143	727089	615368	838811	111721	15.4307
144	611563	499957	723170	111607	19.2462
145	425817	314553	537081	111264	22.2264
146	474781	362127	587434	112653	21.4700
147	684654	572728	796580	111926	16.4565
148	649491	538222	760760	111269	16.4813
149	1030920	919147	1142694	111774	11.6698
150	753852	642358	865345	111493	16.2515

OBS	YHAT	L95	U95	BOUND	BOUNDPC
151	883743	771871	995616	111873	12.8894
152	1200726	1089019	1312432	111707	9.4776
153	852784	741790	963778	110994	12.7385
154	1416056	1303831	1528281	112225	7.8705
155	768150	656838	879462	111312	14.3166
156	1609328	1496837	1721820	112492	6.2329
157	623893	512100	735685	111793	17.4616
158	1124879	1011897	1237862	112982	10.1197
159	511750	398167	625333	113583	21.2918
160	925762	814696	1036827	111065	12.4916
161	1008148	896799	1119496	111349	11.6114
162	928276	817171	1039381	111105	12.1913
163	1222353	1109562	1335145	112791	8.8653
164	1078312	966408	1190217	111905	10.7396
165	641897	530411	753383	111486	17.1915
166	1110314	998259	1222370	112055	10.0277
167	781359	669429	893289	111930	14.6900
168	492122	380115	604129	112007	20.8997
169	746139	634655	857623	111484	14.5984
170	1426109	1313271	1538946	112838	7.8193
171	1153350	1039883	1266817	113467	9.9060
172	819408	707445	931371	111963	14.1582
173	771578	660753	882403	110825	15.1148
174	1061375	949085	1173666	112291	10.7894
175	683642	571808	795477	111835	15.3673
176	982023	871066	1092980	110957	11.6808
177	752142	640455	863829	111687	14.8204
178	441427	329171	553682	112256	22.7472
179	1231935	1120725	1343144	111209	9.2726
180	714300	601429	827171	112871	16.4241
181	567882	456434	679329	111448	18.9290
182	1237691	1125211	1350171	112480	9.1513
183	1032206	921576	1142837	110631	11.0280
184	1079878	966786	1192969	113092	10.6764
185	825298	713950	936647	111349	15.1433
186	889454	778620	1000288	110834	13.1393
187	1463507	1350438	1576577	113069	7.6627
188	1107661	994041	1221281	113620	10.4476
189	820196	708340	932052	111856	15.1967
190	1082518	971336	1193701	111183	10.6516
191	1023628	911629	1135627	111999	11.2772
192	1168166	1056678	1279654	111488	10.0542
193	722263	611229	833298	111035	15.5737
194	686046	574571	797520	111475	16.9687
195	670637	558312	782961	112325	17.6158
196	456534	344497	568571	112037	23.5137
197	500242	387325	613159	112917	20.6087
198	876255	765187	987324	111068	12.9908
199	821838	710442	933233	111396	13.5629
200	964177	852487	1075866	111690	11.9697

OBS	YHAT	L95	U95	BOUND	BOUNDPC
201	1179495	1068506	1290484	110989	9.3122
202	766077	655353	876802	110724	15.1293
203	935800	824491	1047109	111309	12.1025
204	869772	758536	981008	111236	12.7331
205	1325581	1213528	1437635	112053	8.4322
206	1531048	1418723	1643374	112325	7.0885
207	686121	573928	798314	112193	16.5246
208	248224	136177	360272	112048	29.2387
209	1649626	1536862	1762391	112765	6.4482
210	991270	879768	1102772	111502	11.5161
211	1128576	1017908	1239243	110667	9.7605
212	625765	514483	737048	111282	16.8727
213	1086218	975060	1197376	111158	10.4288
214	956289	845254	1067324	111035	11.8447
215	596841	484505	709176	112336	18.3691
216	403392	291539	515246	111854	24.0235
217	943950	833063	1054836	110887	11.5928
218	1636979	1524435	1749523	112544	6.3224
219	1063854	952302	1175405	111551	10.3941
220	597454	485834	709074	111620	18.5245
221	516001	404267	627735	111734	21.7897
222	748034	636446	859622	111588	15.5758
223	1022593	911163	1134024	111430	11.2932
224	730363	617944	842782	112419	16.3718
225	645237	533839	756636	111398	17.2860
226	601232	489676	712788	111556	18.2833
227	856574	745739	967408	110835	13.4088
228	514406	401994	626819	112413	18.6806
229	774704	663250	886158	111454	14.6894
230	627297	516315	738278	110981	17.9588
231	588259	476444	700075	111815	18.9165
232	711440	600103	822777	111337	15.8334
233	1224290	1112112	1336469	112178	8.9251
234	837571	725068	950075	112504	13.3096
235	472912	361361	584463	111551	21.5179
236	982952	871862	1094043	111090	11.6790
237	545858	433070	658645	112787	19.9497
238	918476	805020	1031932	113456	15.6569
239	768299	656209	880389	112090	14.9861
240	556689	443432	669947	113257	18.4772
241	619295	507919	730671	111376	18.8836
242	1271899	1160066	1383733	111834	9.4335
243	561953	450309	673597	111644	19.8488
244	958685	847102	1070267	111582	12.1443
245	1651337	1537819	1764856	113518	6.9196
246	389034	276695	501373	112339	24.8103
247	920206	808447	1031966	111759	12.5110
248	1166005	1052747	1279262	113257	10.3635
249	1441480	1328919	1554042	112562	7.7788
250	877712	766317	989108	111396	13.1322

Appendix F: 95 Percent Prediction Intervals

OBS	YHAT	LOWER	UPPER	BOUND	BOUNDPC
1	688922	577363	800480	111558	16.1932
2	994659	883466	1105853	111193	11.1790
3	626406	514901	737911	111505	17.8008
4	685577	574173	796981	111404	16.2497
5	1268530	1156853	1380207	111677	8.8037
6	943215	831398	1055031	111817	11.8548
7	1349642	1238564	1460720	111078	8.2302
8	807112	694971	919252	112140	13.8940
9	738443	627311	849575	111132	15.0495
10	1792748	1680009	1905487	112739	6.2886
11	1031103	919568	1142637	111534	10.8170
12	584646	473486	695805	111159	19.0131
13	911028	799526	1022529	111502	12.2391
14	796559	682920	910199	113639	14.2662
15	806206	694032	918379	112174	13.9138
16	675784	564685	786882	111099	16.4400
17	682680	571450	793911	111230	16.2932
18	729047	617791	840303	111256	15.2604
19	793368	681099	905637	112269	14.1509
20	1002651	891279	1114024	111372	11.1078
21	817229	705771	928687	111458	13.6385
22	515787	404414	627161	111374	21.5930
23	1067739	955336	1180142	112403	10.5272
24	1025130	914171	1136088	110958	10.8238
25	876778	763480	990076	113298	12.9221
26	999614	888104	1111124	111510	11.1553
27	1201124	1090025	1312223	111099	9.2496
28	644045	533405	754685	110640	17.1789
29	1020615	909083	1132148	111533	10.9280
30	1077427	965931	1188924	111496	10.3484
31	798061	686293	909828	111768	14.0049
32	616600	504587	728614	112013	18.1663
33	1079446	968120	1190771	111325	10.3132
34	1184315	1073338	1295292	110977	9.3706
35	981173	870271	1092076	110903	11.3031
36	698801	587140	810461	111660	15.9788
37	734388	623153	845623	111235	15.1466
38	696680	584990	808370	111690	16.0317
39	943166	831470	1054863	111697	11.8427
40	1199272	1086650	1311895	112623	9.390[illegible]
41	633409	521863	744956	111547	17.6105
42	1195173	1083778	1306568	111395	9.3204
43	1022214	910441	1133988	111773	10.9344
44	401272	287922	514623	113351	28.2478
45	774465	662508	886422	111957	14.4560

OBS	YHAT	LOWER	UPPER	BOUND	BOUNDPC
46	1314555	1201456	1427654	113099	8.6036
47	818983	707522	930443	111461	13.6096
48	472207	359708	584706	112499	23.8241
49	914355	800513	1028197	113842	12.4505
50	508221	397102	619341	111120	21.8644
51	971528	860017	1083038	111510	11.4778
52	429225	317613	540837	111612	26.0032
53	839856	728651	951062	111206	13.2410
54	1068098	957263	1178934	110836	10.3769
55	682984	571861	794108	111124	16.2703
56	424845	311889	537801	112956	26.5876
57	781112	668825	893399	112287	14.3753
58	307868	196040	419696	111828	36.3234
59	765967	653671	878263	112296	14.6607
60	995073	884218	1105927	110854	11.1403
61	1139789	1026971	1252606	112818	9.8981
62	1100527	989029	1212026	111498	10.1313
63	676939	565037	788840	111901	16.5305
64	1624398	1512427	1736369	111971	6.8931
65	546143	434289	657997	111854	20.4807
66	960015	848710	1071321	111305	11.5941
67	1114024	1002447	1225601	111577	10.0157
68	1404791	1292079	1517502	112711	8.0234
69	420162	308117	532206	112045	26.6670
70	567627	455319	679935	112308	19.7855
71	875972	764799	987146	111174	12.6915
72	857008	745403	968613	111605	13.0226
73	1014995	903322	1126669	111674	11.0024
74	345073	233484	456663	111589	32.3379
75	1293971	1182303	1405639	111668	8.6299
76	1246911	1133006	1360815	113904	9.1349
77	947033	835763	1058302	111269	11.7493
78	327006	215459	438553	111547	34.1115
79	994080	882358	1105802	111722	11.2387
80	618313	506990	729637	111324	18.0044
81	897563	786565	1008561	110998	12.3666
82	1386031	1273441	1498621	112590	8.1232
83	305402	192640	418164	112762	36.9224
84	1124839	1012252	1237426	112587	10.0092
85	527457	415644	639270	111813	21.1985
86	1541890	1428712	1655068	113178	7.3402
87	822883	709800	935967	113084	13.7424
88	692110	580595	803625	111515	16.1123
89	943863	832207	1055518	111655	11.8296
90	567978	456951	679005	111027	19.5478
91	463178	351303	575052	111875	24.1537
92	919791	808458	1031124	111333	12.1041
93	907955	795981	1019929	111974	12.3325
94	1072562	961286	1183837	111276	10.3747
95	1431299	1319218	1543380	112081	7.8307

OBS	YHAT	LOWER	UPPER	BOUND	BOUNDPC
96	533916	422818	645015	111099	20.8083
97	1589054	1474057	1704051	114997	7.2368
98	1239544	1127924	1351164	111620	9.0050
99	877387	764479	990294	112908	12.8686
100	989966	878881	1101051	111085	11.2211
101	831168	719894	942442	111274	13.3877
102	717142	605955	828329	111187	15.5042
103	1287864	1175426	1400303	112438	8.7306
104	737194	625342	849045	111852	15.1726
105	816664	705044	928284	111620	13.6678
106	1108932	995023	1222842	113909	10.2720
107	776429	664728	888129	111701	14.3864
108	677909	566535	789283	111374	16.4290
109	1228041	1116013	1340069	112028	9.1225
110	1108830	997254	1220405	111576	10.0625
111	1336422	1223710	1449135	112712	8.4339
112	1077947	965299	1190595	112648	10.4502
113	540461	429630	651291	110831	20.5067
114	1030372	918823	1141921	111549	10.8261
115	303656	190270	417041	113385	37.3401
116	1422229	1310106	1534351	112123	7.8836
117	601993	489888	714098	112105	18.6224
118	980022	868348	1091697	111675	11.3951
119	1104599	992985	1216214	111615	10.1046
120	345464	233043	457885	112421	32.5420
121	975948	865262	1086634	110686	11.3414
122	968137	855626	1080648	112511	11.6214
123	1077552	965868	1189236	111684	10.3646
124	518956	406805	631108	112151	21.6109
125	1384091	1271778	1496403	112312	8.1145
126	709744	598256	821232	111488	15.7082
127	1465456	1353782	1577131	111675	7.6205
128	1038005	926696	1149314	111309	10.7234
129	1079343	967033	1191653	112310	10.4054
130	677450	565515	789385	111935	16.5230
131	946015	834040	1057989	111975	11.8365
132	1193780	1082507	1305052	111272	9.3210
133	1757033	1643682	1870385	113351	6.4513
134	815330	704287	926373	111043	13.6193
135	665860	554690	777029	111170	16.6957
136	1069368	955811	1182924	113556	10.6190
137	976777	865224	1088329	111553	11.4205
138	878369	766866	989872	111503	12.6943
139	1181813	1068659	1294968	113155	9.5747
140	1109574	996736	1222412	112838	10.1695
141	1082523	970428	1194619	112095	10.3550
142	894948	783887	1006009	111061	12.4098
143	727089	615368	838811	111721	15.3655
144	611563	499957	723170	111607	18.2494
145	425817	314553	537081	111264	26.1295

OBS	YHAT	LOWER	UPPER	BOUND	BOUNDPC
146	474781	362127	587434	112653	23.7274
147	684654	572728	796580	111926	16.3478
148	649491	538222	760760	111269	17.1318
149	1030920	919147	1142694	111774	10.8421
150	753852	642358	865345	111493	14.7898
151	883743	771871	995616	111873	12.6589
152	1200726	1089019	1312432	111707	9.3033
153	852784	741790	963778	110994	13.0155
154	1416056	1303831	1528281	112225	7.9252
155	768150	656838	879462	111312	14.4910
156	1609328	1496837	1721820	112492	6.9900
157	623893	512100	735685	111793	17.9186
158	1124879	1011897	1237862	112982	10.0439
159	511750	398167	625333	113583	22.1950
160	925762	814696	1036827	111065	11.9972
161	1008148	896799	1119496	111349	11.0449
162	928276	817171	1039381	111105	11.9690
163	1222353	1109562	1335145	112791	9.2274
164	1078312	966408	1190217	111905	10.3777
165	641897	530411	753383	111486	17.3682
166	1110314	998259	1222370	112055	10.0922
167	781359	669429	893289	111930	14.3250
168	492122	380115	604129	112007	22.7600
169	746139	634655	857623	111484	14.9415
170	1426109	1313271	1538946	112838	7.9123
171	1153350	1039883	1266817	113467	9.8380
172	819408	707445	931371	111963	13.6639
173	771578	660753	882403	110825	14.3634
174	1061375	949085	1173666	112291	10.5797
175	683642	571808	795477	111835	16.3587
176	982023	871066	1092980	110957	11.2989
177	752142	640455	863829	111687	14.8492
178	441427	329171	553682	112256	25.4302
179	1231935	1120725	1343144	111209	9.0272
180	714300	601429	827171	112871	15.8016
181	567882	456434	679329	111448	19.6252
182	1237691	1125211	1350171	112480	9.0879
183	1032206	921576	1142837	110631	10.7179
184	1079878	966786	1192969	113092	10.4726
185	825298	713950	936647	111349	13.4919
186	889454	778620	1000288	110834	12.4609
187	1463507	1350438	1576577	113069	7.7259
188	1107661	994041	1221281	113620	10.2576
189	820196	708340	932052	111856	13.6377
190	1082518	971336	1193701	111183	10.2707
191	1023628	911629	1135627	111999	10.9414
192	1168166	1056678	1279654	111488	9.5439
193	722263	611229	833298	111035	15.3732
194	686046	574571	797520	111475	16.2489
195	670637	558312	782961	112325	16.7489

OBS	YHAT	LOWER	UPPER	BOUND	BOUNDPC
196	456534	344497	568571	112037	24.5409
197	500242	387325	613159	112917	22.5724
198	876255	765187	987324	111068	12.6753
199	821838	710442	933233	111396	13.5545
200	964177	852487	1075866	111690	11.5840
201	1179495	1068506	1290484	110989	9.4099
202	766077	655353	876802	110724	14.4534
203	935800	824491	1047109	111309	11.8946
204	869772	758536	981008	111236	12.7891
205	1325581	1213528	1437635	112053	8.4532
206	1531048	1418723	1643374	112325	7.3365
207	686121	573928	798314	112193	16.3517
208	248224	136177	360272	112048	45.1397
209	1649626	1536862	1762391	112765	6.8358
210	991270	879768	1102772	111502	11.2484
211	1128576	1017908	1239243	110667	9.8059
212	625765	514483	737048	111282	17.7834
213	1086218	975060	1197376	111158	10.2335
214	956289	845254	1067324	111035	11.6110
215	596841	484505	709176	112336	18.8217
216	403392	291539	515246	111854	27.7282
217	943950	833063	1054836	110887	11.7471
218	1636979	1524435	1749523	112544	6.8751
219	1063854	952302	1175405	111551	10.4856
220	597454	485834	709074	111620	18.6826
221	516001	404267	627735	111734	21.6538
222	748034	636446	859622	111588	14.9175
223	1022593	911163	1134024	111430	10.8968
224	730363	617944	842782	112419	15.3922
225	645237	533839	756636	111398	17.2647
226	601232	489676	712788	111556	18.5546
227	856574	745739	967408	110835	12.9393
228	514406	401994	626819	112413	21.8529
229	774704	663250	886158	111454	14.3866
230	627297	516315	738278	110981	17.6920
231	588259	476444	700075	111815	19.0078
232	711440	600103	822777	111337	15.6495
233	1224290	1112112	1336469	112178	9.1627
234	837571	725068	950075	112504	13.4321
235	472912	361361	584463	111551	23.5882
236	982952	871862	1094043	111090	11.3017
237	545858	433070	658645	112787	20.6624
238	918476	805020	1031932	113456	12.3526
239	768299	656209	880389	112090	14.5893
240	556689	443432	669947	113257	20.3448
241	619295	507919	730671	111376	17.9844
242	1271899	1160066	1383733	111834	8.7927
243	561953	450309	673597	111644	19.8671
244	958685	847102	1070267	111582	11.6391
245	1651337	1537819	1764856	113518	6.8743

OBS	YHAT	LOWER	UPPER	BOUND	BOUNDPC
246	389034	276695	501373	112339	28.8764
247	920206	808447	1031966	111759	12.1450
248	1166005	1052747	1279262	113257	9.7133
249	1441480	1328919	1554042	112562	7.8088
250	877712	766317	989108	111396	12.6916

Appendix G: Model-S Validation Data

Column 1 - observation number (251-300);

Column 2 - TOTCOST figure generated by Model-A;

column 3 - point estimate of TOTCOST called COSTHAT generated by Model-S;

Column 4 - the difference of the two (column 2 - column 3);

column 5 - the difference expressed as a percent of TOTCOST;

1	2	3	4	5
OBS	TOTCOST	COSTHAT	DIFF	PERDIFF
251	695796	658914	36882	0.05301
252	1060244	1085562	-25318	-0.02388
253	1044413	1044454	-41	-0.00004
254	744470	797767	-53297	-0.07159
255	1230937	1259899	-28962	-0.02353
256	802437	843661	-41224	-0.05137
257	838258	948801	110543	-0.13187
258	1084530	1086562	-2032	-0.00187
259	512303	547499	-35196	-0.06870
260	631300	608668	22632	0.03585
261	1130608	1172114	-41506	-0.03671
262	1465433	1421846	43587	0.02974
263	1197534	1247163	-49629	-0.04144
264	1037298	1031407	5891	0.00568
265	554400	530746	23654	0.04267

1	2	3	4	5
OBS	TOTCOST	COSTHAT	DIFF	PERDIFF
266	339264	153774	185489	0.54674
267	472527	414314	58212	0.12319
268	1367699	1309195	58504	0.04278
269	601497	584518	16979	0.02823
270	714295	695048	19247	0.02695
271	597962	615868	-17906	-0.02994
272	1094512	1164346	-69834	-0.06380
273	923530	896961	26570	0.02877
274	888978	950216	-61238	-0.06889
275	1106653	1111347	-4694	-0.00424
276	551507	522970	28536	0.05174
277	550713	539170	11544	0.02096
278	982094	1054406	-72312	-0.07363
279	1200391	1237092	-36701	-0.03057
280	978053	989565	-11512	-0.01177
281	527517	527183	334	0.00063
282	601191	573661	27530	0.04579
283	456575	334403	122172	0.26758
284	629188	615957	13232	0.02103
285	1130761	1135019	-4258	-0.00377
286	986194	1053595	-67402	-0.06835
287	481462	341183	140280	0.29136
288	1562784	1469976	92808	0.05939
289	1208535	1187327	21208	0.01755

1	2	3	4	5
OBS	TOTCOST	COSTHAT	DIFF	PERDIFF
290	449687	365296	84391	0.18767
291	682577	640799	41778	0.06121
292	1175174	1203270	-28096	-0.02391
293	462763	336240	126524	0.27341
294	552021	497535	54486	0.09870
295	923818	900184	23634	0.02558
296	995474	1033998	-38524	-0.03870
297	1096033	1103370	-7337	-0.00669
298	1118050	1150632	-32582	-0.02914
299	654990	669520	-14529	-0.02218
300	956316	982817	-26501	-0.02771

Bibliography

1. Baker, Capt Michael D. and 1Lt Bruce B. Johnson. An Analysis of Information Sources for the Estimation of Life Cycle Operating and Maintenance Costs of Turbine Engines. MS thesis, AFIT/LSSR/11-77A. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-patterson AFB OH, August 1977 (ADA044082).

2. Banks, Jerry and John S. Carson, II. Discrete-Event System Simulation. Princeton NJ: Prentice-Hall, Inc., 1984.

3. Blanchard, Benjamin S. Design and Manage to Life Cycle Cost. Portland OR: MA Press, 1978.

4. Cox, Brenda H. Jet Engine Operating and Support Cost Estimating Relationship Development. MS thesis, AFIT/GLM/LSY/85S-8. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, September 1985 (AD-A161683).

5. Davidson, Capt George H. and Capt Raymond E. Griffiths. An Identification and Characterization of Cost Models/Techniques Used by Air Force Logistics Command to Estimate Jet Engine Operation and Support Cost. MS thesis, AFIT/LSSR/77A-01. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, August 1977 (AD-A044083).

6. Department of the Air Force. Life Cycle Cost Management Program. AFR 300-11. Washington: HQ USAF, 22 February 1978.

7. -----. Logistics Support Cost (LSC) Model User's Handbook, Version 1.1. Wright-Patterson AFB OH: HQ Air Force Logistics Command (AFALD/XRSC), January 1979.

8. -----. The Super Operating and Support Cost Model (SOSCM). Wright-Patterson AFB OH: Aeronautical Systems Division (ASD/YZ), January 1979.

9. Dover, Lawrence E. and Capt Billy E. Oswald. A Summary and Analysis of Selected Life Cycle Costing Techniques and Models. MS thesis, AFIT/SLSR/18-74B. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, August 1974 (AD-787183).

10. Earles, Don. Class handout distributed in QMT-353, Life Cycle Costing. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, August 1985.

11. Earles, Mary Eddins. Factors, Formulas and Structures for Life Cycle Costing. Boston MA: Eddins-Earles, 1981.

12. Emmelhainz, Margaret A. "Life Cycle Costs: Acquisition vs Support Costs," AFIT AOG Quarterly, 3 (No. 4): 8-9 (winter 1982-83).

13. Fisher, Gene H. Cost Considerations in Systems Analysis. New York NY: American Elsevier Publishing Company, 1974.

14. Kankey, Roland D. "Notes on Ownership Cost," Paper for Seminar in Cost Analysis. Wright-Patterson AFB OH: School of Systems and Logistics, Air Force Institute of Technology (AU), July 1984.

15. Markowitz, Herbert and Gordon P. Wright. Statistics for Management and Economics. Columbus OH: Charles E. Merrill Publishing Company, 1985.

16. May, Maj Thomas E. Operating and Support Cost Estimating, A Primer. Wright-Patterson AFB OH: Life Cost Management Division, ASD, May 1982.

17. Nelson, Eric E. and Capt William Smith. A Taxonomy of Cost Estimating Characteristics as Applied to an Aircraft Replenishment Investment Spares Model. MS thesis, AFIT/SLSR 01-76A. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, August 1976 (AD-A030239).

18. Nelson, J. R. Life-Cycle Analysis of Aircraft Turbine Engines: Executive Summary, March 1977. Contract F49620-77-C-0023. Santa Monica CA: Rand Corporation, March 1977 (AD-A039062).

19. Neter, John and others. Applied Linear Regression Models. Homewood IL: Irwin Publishing Company, 1984.

20. Pitterle, Capt Elise K. An Identification of Operating and Support Cost Drivers for Command, Control, Communications, and Intelligence Systems. MS thesis, AFIT/GSM/LSY/85S-26. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, September 1985 (AD-A162280).

21. Pritsker, A. Alan B. Introduction to Simulation and Slam II. Richmond IN: Systems Publishing Corporation, 1984.

22. Recktenwalt, Thomas J. The Air Force Visibility and Management of Operating and Support Costs: A Practical Approach to O&S Costing: Staff Report. Wright-Patterson AFB OH: Office of VAMOSC, HQ AFLC, September 1982 (AD-A125986).

23. SAS User's Guide: Basics (Fifth Edition). North Carolina: SAS Institute, 1985.

24. Scherrer, Capt John D. Life Cycle Costing. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, August 1977.

25. Seldon, Robert M. Life Cycle Costing: A Better Method of Government Procurement. Boulder CO: Westview Press, 1979.

VITA

1Lt Rajiv S. Verma was born on 5 April 1960 in Begusarai, India. He graduated from North High School in Arkon, Ohio and attended the University of Akron from which he received a Bachelor of Science degree in Business Management. After a year as a management trainee at Firestone Rubber & Tire Company, he attended graduate school at the University of Akron from which he received an M.B.A. in March 1982. Upon being commissioned in the USAF from the Officers' Training School in February 1984, he was assigned to the 379th Heavy Bombardment Wing where he served as Chief, Cost and Management Analysis until entering the School of Systems and Logistics, Air Force Institute of Technology, in June 1986.

Permanent Address: 1389 Berkshire Road
Stow, Ohio 44224

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION: UNCLASSIFIED

1b. RESTRICTIVE MARKINGS: AD-A186923

2a. SECURITY CLASSIFICATION AUTHORITY:

2b. DECLASSIFICATION / DOWNGRADING SCHEDULE:

3. DISTRIBUTION / AVAILABILITY OF REPORT: Approved for public release; distribution unlimited.

4. PERFORMING ORGANIZATION REPORT NUMBER(S): AFIT/GSM/LSQ/87S-35

5. MONITORING ORGANIZATION REPORT NUMBER(S):

6a. NAME OF PERFORMING ORGANIZATION: School of Systems and Logistics

6b. OFFICE SYMBOL (If applicable): AFIT/LSQ

7a. NAME OF MONITORING ORGANIZATION:

6c. ADDRESS (City, State, and ZIP Code): Air Force Institute of Technology Wright-Patterson AFB, Ohio 45433-6583

7b. ADDRESS (City, State, and ZIP Code):

8a. NAME OF FUNDING / SPONSORING ORGANIZATION:

8b. OFFICE SYMBOL (If applicable):

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER:

8c. ADDRESS (City, State, and ZIP Code):

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO	WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification): THE USE OF COST ESTIMATING RELATIONSHIPS VERSUS ACCOUNTING MODELS FOR ESTIMATING MAINTENANCE AND REPAIR COSTS: A METHODOLOGY DEMONSTRATION

12. PERSONAL AUTHOR(S): Rajiv S. Verma, B.S., 1Lt, USAF

13a. TYPE OF REPORT: MS Thesis

13b. TIME COVERED: FROM ______ TO ______

14. DATE OF REPORT (Year, Month, Day): 1987 September

15. PAGE COUNT: 167

16. SUPPLEMENTARY NOTATION:

17. COSATI CODES

FIELD	GROUP	SUB-GROUP
12	03	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number): Life Cycle Cost, Aircraft Maintenance, Cost Analysis, Regression Analysis

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Thesis Chairman: Richard L. Murphy
Assistant Professor of Quantitative Management

Approved for public release: IAW AFR 190-1.
Lynn E. Wolaver 24 Sep 87
Dean for Research and Professional Development
Air Force Institute of Technology
Wright-Patterson AFB OH 45433

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT: ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED

22a. NAME OF RESPONSIBLE INDIVIDUAL: Richard L. Murphy

22b. TELEPHONE (Include Area Code): 513-255-8410

22c. OFFICE SYMBOL: AFIT/LSM

Block 19.

Abstract

. This thesis demonstrated a methodology of developing a Cost Estimating Relationship (CER) that is capable of generating nearly the same cost estimates as an accounting type of cost model. A cost model was first developed that estimated annual recurring maintenance and repair associated costs of a jet engine. This model used 51 input variables and 30 equations and represented an accounting approach to cost estimating with input requirements at low levels of detail. Using techniques of multiple linear regression, a CER was developed that used only seven aggregated variables to estimate the same cost at an acceptable level of accuracy.

The emphasis in this thesis is on the demonstration of a methodology that can be used to develop CERs. Both the accounting type cost model and the CER in this thesis are exclusively for the validation of a methodology and were developed using an artificially generated data base. As such they are not valid for any cost estimation purposes.

END

FEb.

1988

DTIC